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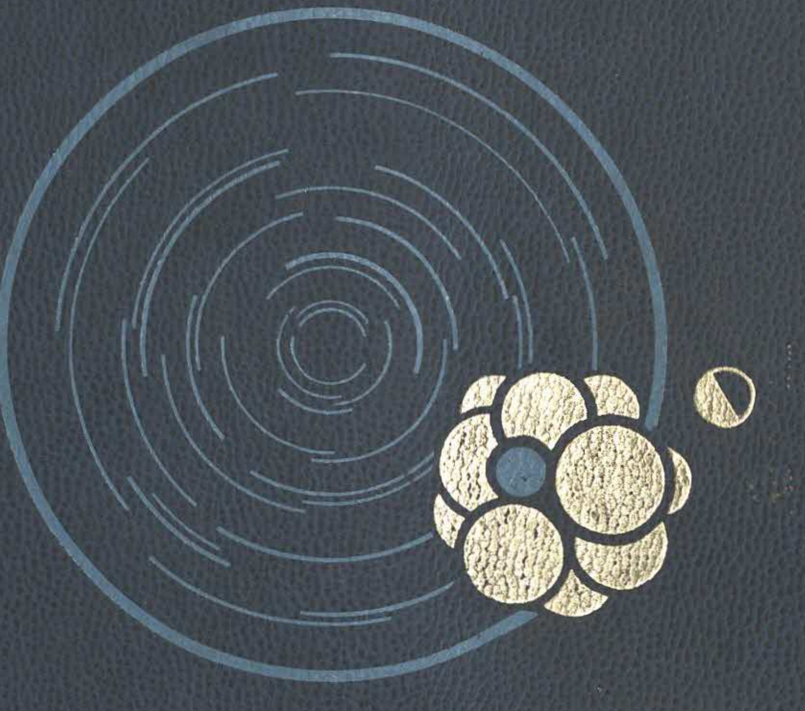
Illustrated World of Science Encyclopedia

Biography II:
LILIENTHAL to Z

INDEX



THE WORLD OF SCIENCE

THE WORLD OF SCIENCE

VOLUME

20

BIOGRAPHY II

Lilienthal *to* Z

with

The Illustrated Science Dictionary
and the Complete Index to Volumes 1 through 20

CREATIVE WORLD PUBLICATIONS, INC.
CHICAGO

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LILIENTHAL, OTTO (1848–1896)

The German aeronautical pioneer Otto Lilienthal made two fundamental contributions to the conquest of the air: with materials that were suitably light and strong, he built a first flying machine; and he experimented with the most natural driving power—the force of gravity. His machine was a primitive form of glider, which hovered in the air but, unlike a sailplane, descended too rapidly for the rising air currents to lift it up again. For Lilienthal this rudimentary aircraft sufficed to show that, with time and perseverance, man could solve the problems of flight.

Lilienthal's passion for flying dated from his boyhood at Anklam, in Prussian Pomerania; and risks, failures, or lack of means could not discourage him. Otto and his brother, Gustav, had lost their father when they were still quite young, and their mother had been forced to give piano lessons to support them. She had always given her sons the freedom to pursue their hobby and had often encouraged them in their research and boosted their enthusiasm.

The aerodynamic studies of Sir George Cayley (1773–1857) had contained the basic principles of flying, though they did not go so far as to indicate the exact process to be followed. During the second half of the nineteenth century the subject of flying was still a controversial one. Some people thought that man would fly someday but had not the slightest idea of how. Others maintained that human flight would never be possible. Moreover, there had been a new development: by means of hydrogen, man had managed to rise off the ground. With aerostatic balloons it was, in fact, possible to reach heights of several thousand feet and to study the atmosphere and meteorological phenomena.

By observing the flight of birds, the Lilienthal brothers made a number of fundamental discoveries. Their observation that takeoff can be achieved more easily against the wind convinced them that it would be possible for man to fly if only he had wings at his disposal, and so they turned with great enthusiasm to the first experiment in aeronautical construction. They were still high-school students when they abandoned theory for the first practical attempts, which they undertook at night to avoid being jeered at by their schoolmates. The hot, windless summer nights, however, were not favorable for their machine; and in spite of their energetic efforts, the crude aircraft rose up only slightly and slowly. Circumstances soon forced them to leave the high school for studies of a more practical and profitable nature. Thus, Gustav enrolled in the royal school (the equivalent of a modern technical institute), while Otto entered an industrial school. After graduating with high grades, Otto took a job in a machine factory, first as an ordinary worker and then in the planning and construction office.

Times were hard; but with his first pay, Otto purchased a bundle of cane rods for a new machine: he had discovered that cane was more resistant and much lighter than wood. The wings, consisting of a cane framework covered with canvas, weighed much less than those used in the previous experiments; but they still did not provide enough impetus to keep the monoplane in the air.

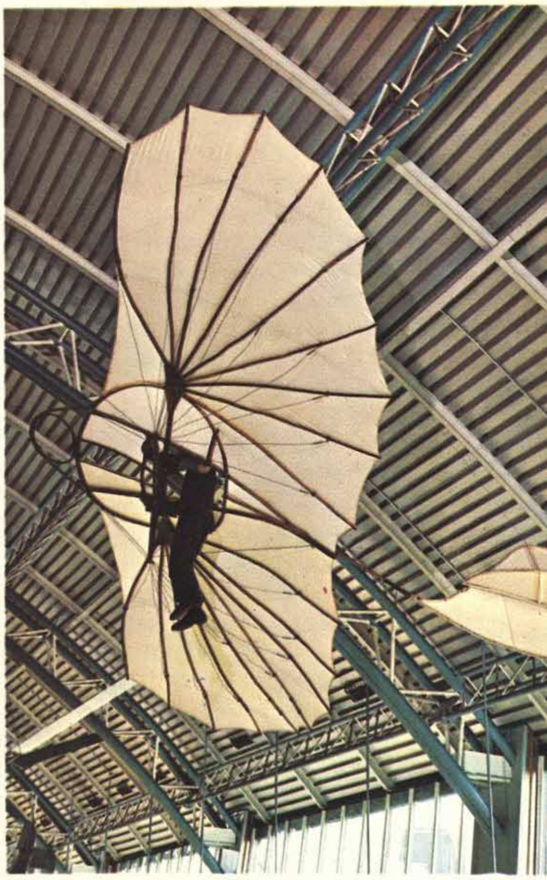
After earning a degree in engineering and taking part in the Franco-Prussian War, Otto returned to his aeronautical research. He reexamined the unsuccessful attempts, made a thorough study of the phenomena of air resistance in relation to the wings and to gliding, and made the fundamental discovery that a slightly arched wing can give a stronger upward thrust than a flat one and at the same time offer less wind resistance. Gustav, who had recently returned from a stay in England, where he had been in touch with the English Aeronautical Society, made some suggestions that proved useful in the construction of a machine to measure the direction and intensity of air resistance. In the autumn of 1874, on the basis of these studies and discoveries, a glider of theirs made a gliding flight upwind. It swayed in the fitful gusts, but its motion was steady even after the releasing of the ropes that had at first guided its course. An enormous step forward had been achieved, but this was only the beginning of a long, arduous road.

Meanwhile, Otto had patented several of his inventions: ships' sirens and steam engines that were as light as it is possible for a steam engine to be. He hoped to be able to use them on his aircraft, but they proved to be too heavy. He had no difficulty, however, in finding buyers for them, since they were extremely useful for other purposes, particularly as they had not been superseded by piston engines.

His improved financial circumstances allowed Otto to marry Agnes Fischer, the young daughter of a mining official whom he had met while on a journey in Saxony, and to leave the firm for which he had been working for ten years and start a small business of his own in 1881. This rapidly expanded, and soon he was able to devote himself more actively to his research. Meticulously he noted down everything that could be useful for the achievement of his aim, and every day brought him fresh knowledge. He built a house on the outskirts of Berlin, and there, in his workshop and on an artificial hill in the garden, he intensified his experiments. He had realized that direct personal experience was necessary for the verifying of his theoretical conclusions: "The invention of a thing," he affirmed, "is nothing; its construction is little more; the testing of it is everything." He hoped to be able to pass from the initial experimental phase of gliding to a second phase of flying with wings that flapped by means of an engine.

Otto Lilienthal

One of Otto Lilienthal's flying machines consisted of two curved wings and a tail and was made of canvas and light cane. The pilot's arms were above the wings, and his legs below.



From 1891 to 1896 his experiments followed one another with increasing frequency and success: from a fixed, vertical type of tail he passed to a horizontal stabilizer tail and then to one with crossed fins, and from the monoplane he progressed to the more complex biplane and finally to the first attempt with a machine with flapping wings and a small engine. Altogether he accomplished a total of more than 2,000 successful flights.

He became a Sunday attraction for the Berliners, and his flights took place in the presence of large crowds. At one such seemingly normal flight, a storm was threatening, and suddenly, unexpectedly, he was flung from a height of about fifty feet. He was picked up with a broken back, and on the following day he died. His last words, in keeping with his short but courageous life, were, "Sacrifices are necessary."

LINDBERGH, CHARLES AUGUSTUS (1902–   )

The U.S. aviator Charles A. Lindbergh made aviation history by being the first man to fly nonstop across the Atlantic. This historic flight, on May 20, 1927, from New York City to Paris, France, made Lindbergh an overnight world hero; but, more important, his accomplishment revealed the possibility of intercontinental flight and led to the quick and extensive expansion of commercial and military aviation.

Lindbergh was born in Detroit, Michigan, the son of a U.S. congressman from Minnesota. His early life was spent in Minnesota and Washington, D.C. In 1922 he entered the University of Wisconsin to study mechanical engineering; but after becoming seriously interested in aviation, he left there to attend a flying school in Lincoln, Nebraska, and then became a cadet in the U.S. Air Service. Upon graduating he became an airmail pilot between Saint Louis and Chicago.

Hearing about a $25,000 prize being offered by financier Raymond B. Orteig to the pilot who would fly nonstop from New York to Paris, France, Lindbergh sought financial backing from a group of Saint Louis businessmen and purchased a small, sturdy monoplane from the Ryan Aeronautical Company of San Diego, California. He named the plane *Spirit of Saint Louis,* in honor of his backers. While ferrying it from San Diego to New York, he set a transcontinental speed record of almost 120 miles per hour.

On the night of May 20, 1927, despite bad weather, Lindbergh took off on the 3,610-mile flight to the French capital from Roosevelt Field on Long Island. After 33½ hours he landed at Le Bourget Airport near Paris a hero and was greeted by cheering thousands. He was decorated by several European governments and on his return to the United States received the Congressional Medal of Honor from President Calvin Coolidge. "Lucky Lindy" became a household term and was even the subject of a popular song.

Lindbergh made several other noteworthy long-distance flights—to Mexico City (1927), to Central America and the Caribbean (1928), and, with his wife, the former Anne Morrow, who later became a known writer, to the Orient (1931). Two years later he flew 30,000 miles around the Atlantic, studying and charting possible air routes across the ocean, and then took on assignments as adviser and consultant to the government and to several airlines still in their infancy.

In 1932 the two-year-old son of the Lindberghs was kidnapped from their home near Hopewell, New Jersey, and murdered in what was one of the most sensational crimes of the 1930s. It became a front-page story again in 1936 when the kidnapper was convicted and executed. The crime resulted in the Lindbergh Law, making it a federal offense to transport a kidnapped victim across a state line.

Because of the overwhelming publicity given the trial and the execution, the Lindberghs moved to Europe, where they remained for four years. While there Lindbergh conducted several experiments with the French surgeon and biologist Alexis Carrel and collaborated with him on a book, *The Culture of Organs* (1938).

After returning to the United States, Lindbergh served as consultant and adviser to several governmental aviation committees during World War II. Following the war the Lindberghs moved to Connecticut to live a quiet, unassuming life away from the public eye.

Lindbergh's books include *We* (1929), *Of Flight and Life* (1948), *The Spirit of Saint Louis* (1953), and *The Wartime Journals* (1970). He was awarded the 1954 Pulitzer Prize for *The Spirit of Saint Louis,* which is an autobiography as well as an account of his 1927 flight to Paris.

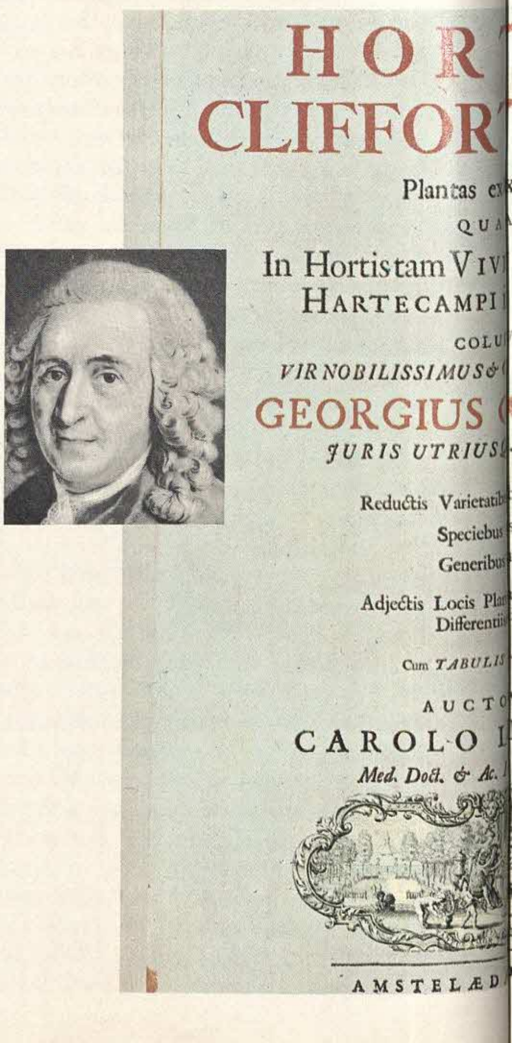
LINNAEUS, CARL (1707–1778)

The nomenclature and descriptions that still form the basis of plant classification were devised by Carl Linnaeus, an eighteenth-century Swedish botanist. The binomial nomenclature (genera and species) that appeared first in Linnaeus' *Species plantarum* (1753) is the internationally accepted way of naming plants.

The Linnaean system of classifying plants was based mainly on the number of stamens and pistils in the flower and the way in which, if not free, they were joined together. Linnaeus recognized that the system was contrived; but at a time when travel and investigation were accelerating the discovery of vegetation, it was a practical method that enabled students to quickly place a plant in a named category. The simplicity of the Linnaean system in itself stimulated botanical collecting. Aside from his rules of nomenclature, the most valuable contributions that Linnaeus made were his careful descriptions of about 6,000 species arranged in genera and his collation of the species he knew with the names and descriptions given by previous botanists, making it possible to trace a plant from one author to another.

Linnaeus systematized not only the plant kingdom but also the animal and mineral. The tenth edition of Volume I of his *Systema naturae* (1758) did for zoo-

Among Carl Linnaeus' many works on plant life was *Hortus Cliffortianus*, which was published in Amsterdam in 1737. This Swedish botanist



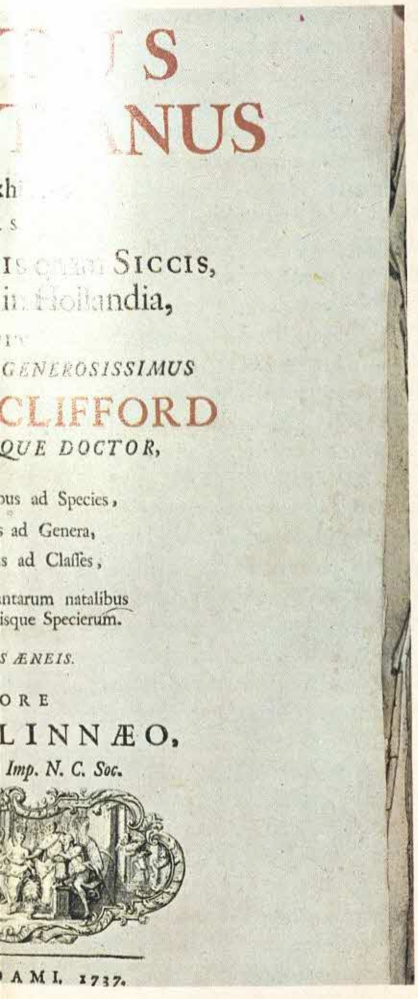
logical nomenclature what *Species plantarum* had done for the botanical. Linnaeus practically created botanical Latin as a technical language.

He was born at South Råshult, Sweden, the son of a clergyman, Nils Ingemarsson, who, inspired by a big linden tree, or *linn*, on the family property, coined for himself the surname Linnaeus. Carl was educated at Växjö and at the universities of Lund and Uppsala. At the latter institution he qualified in medicine and met the veteran botanist Olaf Celsius, who profoundly influenced his future. Linnaeus was appointed lecturer in botany in 1730 and two years later explored in Lapland for the Swedish Academy of Sciences. From 1735 to 1738 he lived in Holland, where he published the results of his journey to Lapland as *Flora Lapponica* (1737). This work was published as *Lachesis Lapponica* in England by Sir James Edward Smith in 1811.

Returning to Sweden in 1738, Linnaeus settled in Stockholm as a practicing physician. He was appointed to the chair of medicine at Uppsala in 1741, but a year later he exchanged it for the chair of botany and thereafter taught and wrote. His works, which number about 180, include *Critica botanica* (1737) and *Philosophia botanica* (1751), in which he explained his methods; two volumes of observations made during journeys in Sweden; and *Hortus Upsaliensis* (1748).

In 1761 Linnaeus was granted a patent of nobility, antedated to 1757, and became known as Carl von Linné. Six years after his death his widow sold his collections and library to Sir J. E. Smith, who had become the first president of the Linnean Society of London, England. When Smith died in 1828, a subscription was raised to purchase the herbarium and library for the society, which still owns them. The Linnea flower was named in Linnaeus' honor.

introduced the binomial nomenclature of plant classification, using a noun for the genus and an adjective for the species.



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LIPMANN, FRITZ ALBERT (1899–)

In 1953 the German-U.S. biochemist Fritz Lipmann won the Nobel Prize in medicine or physiology for his discovery of coenzyme A, a vital substance in cellular metabolism. He shared the prize with the German-British biochemist Sir Hans A. Krebs, who had discovered the citric acid cycle in the metabolism of carbohydrates, protein, and fat. (*See* Sir Hans Adolf Krebs.)

From the time he suspected its existence, it took years for Lipmann to actually isolate and identify coenzyme A (also called CoA, or the coenzyme of acetylation). Early in his career he studied the Pasteur effect, in which tissues utilize fermentation at first but change to oxidation when oxygen is made available. This led to the study of pyruvic acid oxidation and the observation that this process is dependent on inorganic phosphate. He then examined the relationship between acetyl phosphate and acetyl transfer and discovered that he could not produce active acetate from acetyl phosphate without some missing ingredient. After much work he isolated coenzyme A as the acetyl carrier and found that it is present in the extracts of all organs, as well as in microorganisms. In 1947 he finally announced his findings.

Lipmann was born in Königsberg, Germany, and studied medicine at the German universities of Königsberg, Munich, and Berlin. After receiving his doctorate in medicine from Berlin in 1922, he studied chemistry successively with Ernest Laquer in Amsterdam, the Netherlands; Hans Meerwein in Königsberg; and Otto Meyerhof in Berlin.

He received his doctorate in chemistry from Berlin in 1927 and did research with Meyerhof for three years thereafter. In 1931 Lipmann went to the Rockefeller Institute in New York City to work under P. A. Levene, and a year later he joined Albert Fischer at the Kaiser Wilhelm (now Max Planck) Institute in Berlin, Germany. When Fischer fled Germany in 1932, Lipmann followed him to Copenhagen, Denmark, where he worked at the Biological Institute for the Carlsberg Foundation until 1939.

Beginning a new life in the United States, Lipmann became a member of the faculty of the Cornell University Medical School, New York City, in 1939 and a naturalized U.S. citizen in 1944. He served as head of the biochemical research department at Massachusetts General Hospital in Boston from 1941 to 1957. During part of that period, 1949 to 1957, he also served as professor of biological chemistry at the medical school of Harvard University. He returned to the Rockefeller Institute as a member and professor in 1957.

LIPPMANN, GABRIEL (1845–1921)

The French physicist Gabriel Lippmann made important contributions in the fields of electricity, thermodynamics, optics, and photochemistry. He is particularly remembered for his invention of a process of color photography, for which he was awarded the 1908 Nobel Prize in physics.

Lippmann was born to French parents at Hollerich, Luxembourg, but shortly thereafter the family moved to Paris. He was educated at the École Normale there and at the universities of Heidelberg and Berlin in Germany. On his return to Paris in 1875, he joined the faculty of the École Normale. In 1883 he was appointed professor of mathematical physics at the Sorbonne; and in 1886 he became professor of physics there and director of its laboratory of physical research, holding that post until his death at sea during a return trip from Canada.

While at Heidelberg he had become interested in electrocapillarity, which led to his invention of a highly sensitive capillary electrometer. He also stated the principle of the conservation of electricity and invented an astatic galvanometer, a new type of seismograph, and the coelostat for observing a section of the sky for an extended period of time.

His most important work, however, was in the area of photochemistry. He invented the photographic reproduction of color by what is called the Lippmann interference process. His first known reference to color photography was made in a series of lectures in 1886, and seven years later he announced the first successful color photograph of the spectrum. In Lippmann's process of color photography the light was reflected back on itself. He used a photographic plate constructed like the eye of an insect and, without using a lens, produced a negative.

In 1883 he was elected to the Paris Academy of Sciences. He became a foreign member of the Royal Society in 1908.

LISTER, JOSEPH (1827–1912)

Before antiseptic procedures were instituted by the English surgeon Joseph Lister, about half of the patients on whom amputations were performed died of gangrene or other infections; in fact, the mortality rate following all operations was extremely high. Lister conceived the idea of making wounds antiseptic and later of making the operating area, instruments, and all persons present as clean and sterile as possible. For this reason he is universally regarded as the founder of antiseptic surgery.

Lister was born at Upton, Essex, England, the son of Joseph Jackson Lister, the discoverer of the aplanatic foci principle of microscopes, who did much to encourage young Lister in scientific studies. After graduating from University College, London, in 1847, Lister studied medicine at University College Hospital and received his medical degree in 1852. The following year he went to Edinburgh, where at first he worked as a house surgeon and in 1855 became assistant surgeon at the Edinburgh Royal Infirmary. His first major academic appointment came in 1860, when he was appointed professor of surgery at the University of Glasgow; and in 1869 he became professor of clinical surgery at Edinburgh. He returned to England in 1877 and accepted the post of professor of surgery at King's College, London.

After general anesthesia came into wide use, there was an increase in the number of operations performed. The mortality rate following operations, however, was between 40 and 60 percent. At first Lister and most other medical men assumed that oxygen in the air caused sepsis in a wound; but then in 1865, on hearing of Louis Pasteur's discovery that putrefaction is caused by microorganisms in the air, Lister began using carbolic acid as an antiseptic dressing, with a consequent dramatic drop in the death rate from infections following operations and injuries. The results of his method were published in his paper "On the Antiseptic Principle in the Practice of Surgery" (1867). As a further precaution against infection, Lister in 1871 tried spraying the air in the operating room with carbolic acid but soon found that it was sufficient to have a spotlessly clean room, well-scrubbed surgeons and assistants, and instruments sterilized by heat.

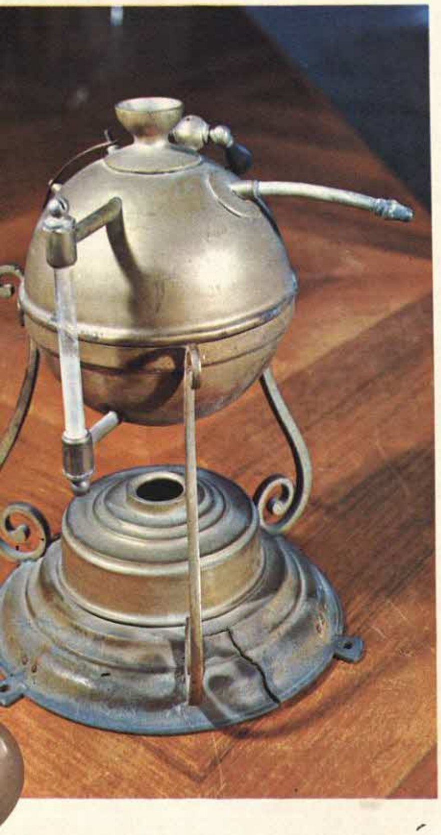
Joseph Lister

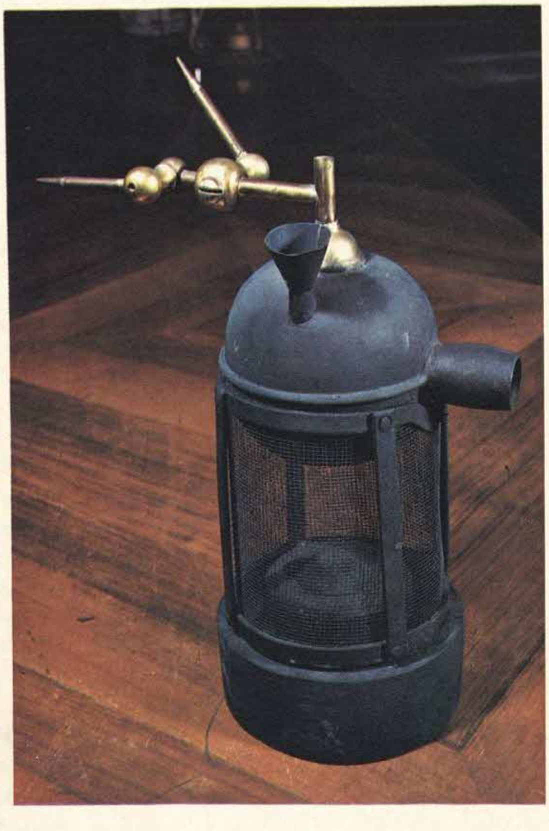
Lister also conducted research on the muscles of the iris, on early stages of inflammation, and on coagulation of blood. He was interested in bacteriology as well and was the first scientist to grow microorganisms in pure culture.

In his surgical work he devised new operations for the excision of the wrist joint and for cancer of the breast, improved surgery of the bladder and urethra, and developed a new technique of amputating through the condyles of the femur. He introduced new surgical instruments, such as the aortic tourniquet, the wire needle, the ear hook, sinus forceps, and forceps for extracting stones from the prostatic urethra. Pursuing his interest in antiseptic surgery, he devoted time to developing sterile ligatures and in 1880 adopted the sulfochromic catgut ligature. He also continued searching for better antiseptic agents, since carbolic acid was irritating to the tissues, and late in his career experimented with the disinfectant properties of compounds containing mercury.

Lister was elected a fellow of the Royal Society in 1860, serving as its president from 1894 to 1900. In 1896 he was president of the British Association for the Advancement of Science. He was one of the founders of the British Institute of Preventive Medicine, which was later renamed in his honor. In 1883 he was made a baronet and in 1897 was raised to the peerage, becoming Baron Lister of Lyme Regis. As such, he was the first medical doctor to become a member of the House of Lords. The Order of Merit was bestowed on him in 1902.

Various equipment was used by Joseph Lister for spraying the air in operating rooms with carbolic acid as a precaution against infection. Later, however, he found that spotlessly clean operating areas and personnel and sterilized instruments were just as effective.





LOBACHEVSKI, NIKOLAI IVANOVICH (1793–1856)

The first mathematician to make a revolutionary contribution to geometry in the twenty centuries since the time of

Euclid was the Russian Nikolai Ivanovich Lobachevski. Even though several mathematicians had independently worked on similar systems, Lobachevski was the first one with the courage to publish, in 1829, a system of non-Euclidean geometry.

He began by contemplating Euclid's fifth axiom, which states that through a given point not on a given line, only one line can be drawn parallel to a given line. This axiom was not self-evident, and for centuries mathematicians had failed to prove it with Euclid's other axioms. In forming his own geometry, Lobachevski discarded the fifth axiom altogether and assumed that at least two parallel lines can be drawn through a given point not on a given line. Using this and some of Euclid's other axioms, he built a self-consistent system of geometry, which many years later found application in theoretical physics and was valuable to Albert Einstein's theory of relativity.

Lobachevski was born to peasant parents at Nizhni-Novogorod (later Gorki), Russia. After the death of his father the family moved to Kazan, where his mother managed to get him enrolled in the newly established university. He graduated from the University of Kazan in 1813 and became an assistant professor of mathematics there the following year. In 1822 he was made a full professor and in 1827 was also appointed rector, or president, of the university.

Not only did he receive little recognition for his work during his lifetime but also was often ridiculed for his unconventional views on geometry. Although an excellent professor and administrator, he was dismissed from his posts at the university in 1846 without cause. Lobachevski's published works include *Principles of Geometry* (1829–1830), *Imaginary Geometry* (1835), and *New Principles of Geometry, with a Complete Theory of Parallels* (1835–1838).

LOEB, JACQUES (1859–1924)

The achievements of the German-American biophysiologist Jacques Loeb in his work on animal tropisms and on artificial parthenogenesis were especially noteworthy. He analyzed the process of egg fertilization and discovered how to fertilize the eggs of certain animals by artificial means.

Loeb was born at Mayen, Germany, and studied at Berlin and Munich before receiving his medical degree from the University of Strasbourg in 1884. From 1886 to 1891 he carried on his work in biology at the University of Würzburg, the University of Strasbourg, and at the Naples Biological Station. After moving to the United States in 1891, he held professorships at Bryn Mawr College, in Pennsylvania (1891–1892), the University of Chicago (1892–1902), and the University of California at Berkeley (1902–1910). He became head of the general physiology division of the Rockefeller Institute for Medical Research, New York City, in 1910. Many of his experiments were conducted at the Marine Biological Laboratory at Woods Hole, Massachusetts.

Jacques Loeb

Being a mechanist, Loeb attempted to demonstrate that tropisms govern the behavior of simple animals in much the same manner as they do plants. He developed a theory of tropism and conceived of complexes of tropisms being responsible for human moral and ethical behavior. He was one of the first experimenters in the field of parthenogenesis and succeeded in producing larvas of sea urchins from unfertilized eggs by making certain changes in their environment. Later he artificially fertilized frog eggs and raised the young frogs to sexual maturity. He also conducted research in comparative physiology and in psychology, producing important work on the physiology of the brain; and his work on the distinction between living and dead matter contributed to the theory of colloidal behavior. Loeb's published works include *The Dynamics of Living Matter* (1906), *The Mechanistic Conception of Life* (1912), *The Organism as a Whole* (1916), and *Regeneration* (1924).

LOEWI, OTTO (1873–1961)

By proving for the first time that chemical substances are involved in the transmission of nerve impulses, Otto Loewi, a German-American pharmacologist, shared the 1936 Nobel Prize in physiology or medicine. His co-winner was Sir Henry H. Dale, British physiologist, who isolated the chemical released at autonomic nerve endings. (*See* Sir Henry Hallett Dale.)

Loewi was born in Frankfurt am Main, Germany, and educated at Strasbourg and Munich. He received his medical degree from the University of Strasbourg in 1896 and was appointed assistant in the pharmacological institute at Marburg in 1898. Three years later he worked for a time under the direction of the British physiologist Ernest H. Starling at University College, London. There Loewi formed a lasting friendship with Dale. In 1904, on his return to Marburg, Loewi was made titular professor of pharmacology, the following year he went to the University of Vienna as associate professor, and in 1909 he became professor of pharmacology at the University of Graz, Austria, serving in that post until 1938.

Studying nerve action, Loewi demonstrated in 1921 that a chemical substance was set free when he stimulated the nerves connected to a frog's heart and that the fluid containing the substance could directly—without nerve action—stimulate another heart. He called the substance *Vagusstoff* ("vagus material") because it was released when he stimulated the vagus nerve. Dale soon proved that *Vagusstoff* was the compound acetylcholine, which he had isolated in 1914.

Two years after Loewi and Dale had won the Nobel Prize, Nazi Germany occupied Austria. Loewi fled first to England but in 1940 emigrated to the United States, where he joined the faculty of New York University College of Medicine. He became a U.S. citizen in 1946.

In addition to his work with the nervous system, Loewi did important research on diabetes, digitalis, and adrenaline. A test that he devised in 1908 for pancreatic function is known as Loewi's test.

LORENTZ, HENDRIK ANTOON (1853–1928)

The Dutch physicist Hendrik A. Lorentz shared the 1902 Nobel Prize in physics with Pieter Zeeman for work on the influence of magnetism on radiation and helped prepare the way for Albert Einstein's special theory of relativity. Lorentz' lifework, though of broad scope, focused on the formulation of a consistent theory for electricity, light, and magnetism. (*See* Pieter Zeeman.)

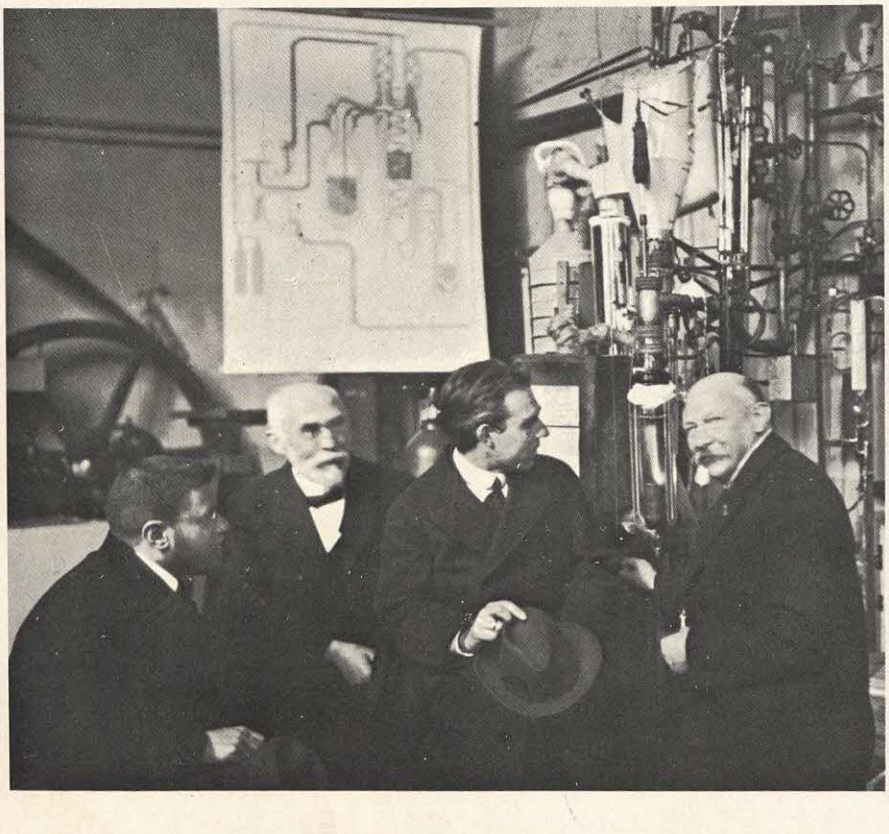
Lorentz was born at Arnhem, the Netherlands, to a family of Rhenish origin. His father, a well-to-do farmer, was comparatively uneducated but gifted with remarkable intelligence and an extraordinary memory, which the son inherited. His mother died when he was nine, and he grew up with a stepmother. She was good to him, and he, in turn, with his calm and happy disposition, gave her little cause for concern.

At school he was fortunate enough to have good teachers, a talent for languages, and, above all, an interest in mathematics and physics, which became his favorite subjects. To gain admittance to Leiden University, he also had to study classical languages, which he did on his own. Before long he had mastered them so thoroughly that forty years later he was still able to compose Latin verses. In 1872 he took a science degree, for which he had studied on his own again, since he did not find group work satisfactory. The thoroughness of his studies and his thirst for knowledge are shown by the fact that on finding James Clerk Maxwell's published works completely unread in the physics laboratory at the university, he took them away, fully convinced that nobody would miss them. To complete his studies he returned to his native town, where he found a job as a night-school teacher that left him enough free time in which to study and finish his thesis.

After receiving his doctorate, he accepted a position at Leiden University as a teacher of experimental and theoretical physics. He also conducted the physics course for doctors for so many years that he was given an honorary degree in medicine.

Lorentz turned to good account the works of Maxwell that he had taken from the physics laboratory at Leiden, assimilating them so thoroughly that he mastered the theory of electromagnetism and even developed it more systematically. The importance of Lorentz' theory of radiation was proved when he was able to explain the Zeeman effect: if light is made to radiate from atoms placed in a magnetic field, the latter emit, not one spectrum line, but two and, in certain circumstances, even three; this is caused by the action of the magnetic field on the movement of the electrons in the atom. Not only did Lorentz give a correct explanation of the phenomenon but also was later proved right in his predictions of polarization effects. In his study of the laws of light, he found a formula that was discovered almost simultaneously by a Danish physicist, Ludwig Valentin Lorenz. Instead of being irritated, Lorentz used to say that he had been involved in an event that was perhaps unique: the simultaneous discovery of the same law by two physicists of the same name. One of Lorentz' most important achievements was the anticipation of the laws of restricted relativity, laws that Lorentz introduced to explain certain mechanical characteristics of the movement of bodies with speeds close to that of light.

After sharing in the 1902 Nobel Prize in physics, Hendrik Lorentz (second from left) attended many conferences, including one at Leiden at which experiments on helium were conducted.



In 1918 Lorentz was named president of the committee for the draining of the Zuider Zee, an important post in the Netherlands, and, though no longer young, set to work with enthusiasm. He studied the winds, currents, and tides and, at great savings to the government, calculated that even with a smaller dike the new basin could contain more water than had been planned. He died before the work was completed, but his methods are still used by the Dutch Water Service.

After Lorentz had become famous, he went abroad a number of times, chiefly to take part in international conferences. He excelled at these because of his knowledge of languages, his amiability, and his rare diplomatic skill. He also presided at the councils of the Solvay Scientific Society several times and was chairman of the Committee of Intellectual Cooperation established by the League of Nations as well. After his death a foundation for the promotion of theoretical physics was created and named in his honor.

LORENZ, KONRAD ZACHARIAS
(1903–   )

One of the most colorful scientists of the twentieth century was the Austrian zoologist Konrad Lorenz, who literally brought his work home with him, allowing all manner of animals to roam freely throughout his house. He carefully observed the behavior of the animals in his home, as well as many forms of wildlife, and was one of the pioneers of modern ethology, basing a new school of study on the idea that the behavior of an animal is a result of adaptive evolution.

Lorenz was born in Vienna, Austria, and early in life developed an interest in wildlife, mainly from his explorations in the countryside surrounding the family's summer home at Altenberg. At the suggestion of his father, a professor at the University of Vienna and a famous orthopedic surgeon, Lorenz took up the study of medicine and in 1928 received his medical degree from the University of Vienna after studying there and at Columbia University in New York. While working as an assistant at the Anatomical Institute in Vienna from 1928 to 1935, he studied zoology and in 1933 obtained his doctorate.

In 1937 Lorenz began lecturing in comparative anatomy and animal psychology at the University of Vienna and was assistant professor there from 1938 until he

Konrad Lorenz

was appointed professor and head of the psychology department at the University of Königsberg, Germany, in 1940. After only a short time, however, he left the latter post to serve as physician in the German army during World War II. He was captured and held as a prisoner of war in the Soviet Union from 1944 to 1948, whereupon he returned to Austria and became head of the Institute of Comparative Ethology at Altenberg in 1949. He remained there until 1951, when he was invited to head the Department of Research in Comparative Ethology at the Max Planck Institute for the Physiology of Behavior in Buldern, Germany. In 1954 he was appointed assistant director of the institute, where he stayed until 1961, when he became director of the Max Planck Institute for the Physiology of Behavior at Seewiesen.

Lorenz studied and wrote about the imprinting and release mechanisms in animals. Of imprinting, Lorenz found that animals raised with a species other than their own have reactions directed toward that species and do not know to what species they belong. Releasers, according to Lorenz, are actions that set off instinctive reactions, such as the gestures of fighting fish that either stimulate or inhibit the urge to fight in another fish of the same species.

Not only did Lorenz write about the behavior of animals, but his books also contain philosophical commentaries on the human condition. Among his published works can be found *King Solomon's Ring* (1952), *Man Meets Dog* (1954), *Evolution and Modification of Behavior* (1966), *On Aggression* (1966), and *Studies in Animal and Human Behavior I* (1969). His film about graylag geese was awarded the Gold Medal of the New York Zoological Society. Lorenz was awarded several honorary degrees from universities in Europe and the United States and was elected to many scientific and professional societies, including Great Britain's Royal Society and the American Academy of Arts and Sciences.

LOVELL, SIR ALFRED CHARLES BERNARD (1913–)

The English astronomer Bernard Lovell was responsible for building, at Jodrell Bank, Cheshire, England, the first giant radio telescope. This became the world's most successful instrument for tracking Earth satellites.

Lovell was born in Oldland Common, Gloucestershire, England, and was educated at the University of Bristol. After receiving his doctorate there in 1936, he joined the faculty of Manchester University as a lecturer in physics. During World War II he served with the Air Ministry Research Establishment—this later became the Telecommunication Research Establishment—where he developed centimetric airborne radar and was head of the British blind bombing and antisubmarine groups.

With a team of associates in 1946–1947, Lovell demonstrated that radar echoes can be picked up from daytime meteor showers, which are invisible by ordinary optical means. By applying radio techniques to meteor activity, Lovell and his team were able to determine orbits and radiants of meteors. Later experiments demonstrated that all meteors are members of the solar system and are not interstellar in origin.

In 1951 Lovell became the first professor of radio astronomy at Manchester University and director of the Jodrell Bank Experimental Station, just outside Manchester, where he began building a giant steerable radio telescope. When completed six years later, it measured 250 feet in diameter and employed the turret rack of a battleship as a steering device. It was finished just in time to track *Sputnik I*, the first man-made satellite, launched by the Soviet Union in October 1957, and afterward was used successfully in tracking other major Earth satellites.

Lovell was elected a fellow of the Royal Society in 1955, received the society's Royal Medal in 1960, and was knighted in 1961. His books include *Radio Astronomy* (1952), *Meteor Astronomy* (1954), *The Exploration of Space by Radio* (1957), *The Individual and the Universe* (1959), and *The Exploration of Outer Space* (1961).

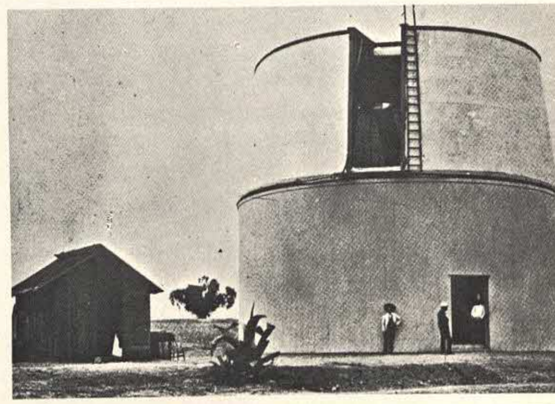
LOWELL, PERCIVAL (1855–1916)

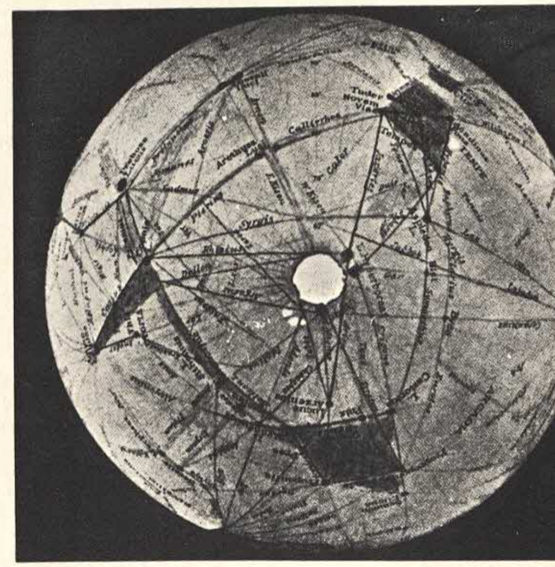
The U.S. astronomer Percival Lowell founded the Lowell Observatory at Flagstaff, Arizona. He is famous also for his observations of the planet Mars and for correctly predicting the existence of the planet Pluto.

Lowell was born to an aristocratic family—his sister was the poet Amy Lowell—in Boston, Massachusetts, and educated at Harvard University, graduating with honors in 1876. From 1877 to 1893 he worked in the business world and spent a considerable amount of time traveling in the Far East, mainly in Japan. During this time he wrote several books on the Orient.

Percival Lowell

When, in 1894, the Lowell Observatory near Flagstaff, Arizona, was completed, Percival Lowell devoted a large part of his studies to observing Mars, with the hope of proving that it was inhabited. In 1905 he plotted a map of Mars showing its north pole.





Having always had an interest in mathematics, and with his curiosity about astronomy aroused by the discovery of "canals" on Mars, he decided to devote his time and money to observing the solar system. After searching, he found the perfect place for his observatory: a high, remote spot near Flagstaff, where the clear desert air was ideal for searching the skies. In 1894 the Lowell Observatory was completed, and he began observing Mars. At first he used an eighteen-inch refracting telescope but later changed to a twenty-four-inch refractor. His most famous work relating to Mars concerned the canals. He painstakingly charted many of these canals and concluded that they were built and used by intelligent beings for the purpose of irrigation. Even though he was sincere in his work, his theory of life on Mars proved to be highly doubtful, and many of his observations of canals are now thought to have been a type of optical illusion.

The other major contribution of Lowell was his prediction of the existence of Planet X, which was later named Pluto. Because of the perturbations of Uranus, he calculated that there was a planet beyond Neptune; and at the Lowell Observatory, on March 12, 1930, years after Lowell's death, Pluto was discovered in a position close to that predicted by Lowell.

Lowell made many important observations about the other planets also, such as the discovery of new divisions in the rings of Saturn, and engaged in the spectroscopic study of clusters and nebulas. In 1902 he was made professor of astronomy at the Massachusetts Institute of Technology. His publications include *Mars* (1895), *Mars and Its Canals* (1906), *Mars as the Abode of Life* (1908), *The Evolution of Worlds* (1909), and *The Genesis of the Planets* (1916).

LUMIÈRE, LOUIS JEAN (1864–1948) and AUGUSTE MARIE LOUIS NICOLAS (1862–1954)

The first satisfactory motion-picture camera and projector were developed by Louis Jean Lumière and his brother Auguste. Working as a team, the French scientists, inventors, and manufacturers also introduced a new kind of photographic colorplate and a direct-color process.

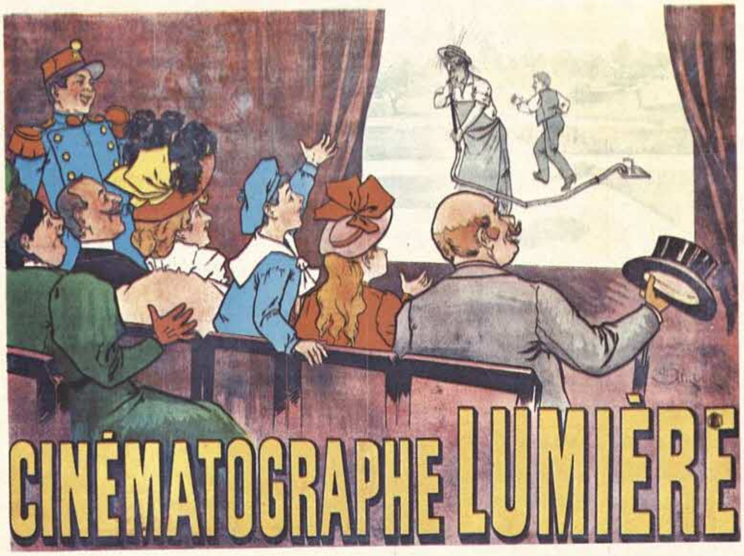
Both Louis and Auguste were born at Besançon, France. Expanding the dry-plate factory founded at Lyons in 1882 by their father, Antoine Lumière, they began manufacturing photographic paper and roll film in 1887. In 1895 they built and patented their Cinématographe—a camera, projector, and printer combined —which was the basis of nearly all modern motion-picture apparatus. Its design incorporated an intermittent claw movement with perforated 35 millimeter film of Lumière manufacture.

In June 1895 the Lumières showed several films, each a few minutes long; and the first public cinema performance before a paying audience took place in Paris, France, the following December. Soon Cinématographes were taking pictures and giving shows throughout Europe. In June 1896 the machines were introduced into the United States to compete with Thomas A. Edison's Kinetoscope, which did not project the image but, instead, provided for viewing the moving pictures through a peephole.

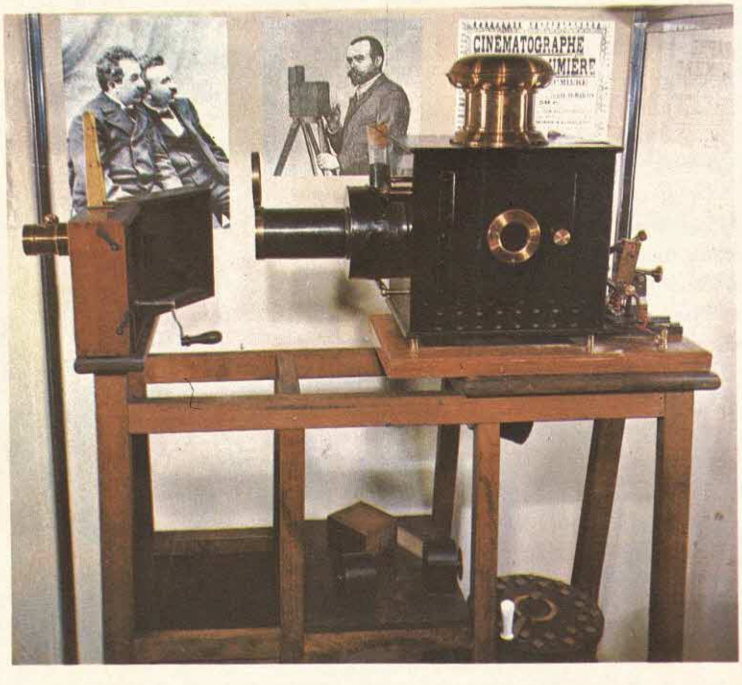
Another innovation, the Photorama, was presented by the brothers in 1900 at the International Exhibition in Paris. This was a 360-degree panoramic projection device. The Lumières also invented a stereo motion-picture process that gave a three-dimensional effect when viewed through special eyeglasses, but it was not introduced until 1935.

In the field of color photography, the Lumières patented Autochrome colorplates in 1904. The plates were coated with starch grains dyed green, red, and blue to act as a color screen. This resulted in a transparency composed of small dots of primary colors that gave the effect of mixed colors. Introduced commercially in 1907, the Autochrome method became the first popular direct-color process.

In 1895 Louis Lumière and his brother Auguste patented their Cinématographe, a camera, projector, and printer combination. The first public cinema performance took place in Paris in December 1895, and soon there were Cinématographe shows throughout Europe.



Louis Jean Lumière



The Lumières wrote many papers on their chemical and photographic investigations. Auguste was also active in the field of biology.

LURIA, SALVADOR EDWARD
(1912–   )

The American biologist Salvador E. Luria was one of three scientists who won the 1969 Nobel Prize in medicine or physiology. The other two were Max Delbrück and Alfred D. Hershey. (*See* Max Delbrück; Alfred Day Hershey.)

Luria became interested in the subject of his ultimate expertise during a traffic jam many years ago in his native Italy. Sitting in a stalled streetcar in Rome, he started talking to a passenger next to him and ended up working for him.

In 1940 he moved to the United States, where, at Vanderbilt University, Nashville, Tennessee, he joined Delbrück, who was studying the interaction of viruses and bacteria. Their research involved bacteriophages, prolific viruses that infect bacterial cells rather than ordinary ones. The men created models that mathematically described how phages multiply. Their work revolutionized molecular biology, particularly as it relates to the viral diseases. Even after they left Vanderbilt, Luria and Delbrück continued to cooperate. Hershey joined them in 19[illegible], and the three scientists became known as the Phage Group.

Of the three, Luria probably was the most politically active. He was pleased, for example, that his Nobel Prize was announced on October 16, not October 15, the day that he was taking part in a national Vietnam moratorium. He said that he would use his share of the award money "for myself, my family, and a number of antiwar activities."

Luria was born in Turin, Italy, and studied medicine there and physics and radiology in Rome and Paris, France, before moving to the United States, where he was naturalized in 1947. In the United States he conducted research and taught at Columbia University's College of Physicians and Surgeons, the Carnegie Institution, the University of Indiana, the University of Illinois, and the Massachusetts Institute of Technology, where he became head of the microbiology department.

He published *General Virology* in 1953 and was elected to the National Academy of Sciences in 1960. In keeping with his belief that the purpose of science is to further humanitarian ends, he also did sculpturing and taught world literature to graduate scientists.

LUSSAC. See Gay-Lussac, Joseph Louis.

LWOFF, ANDRÉ (1902–   )

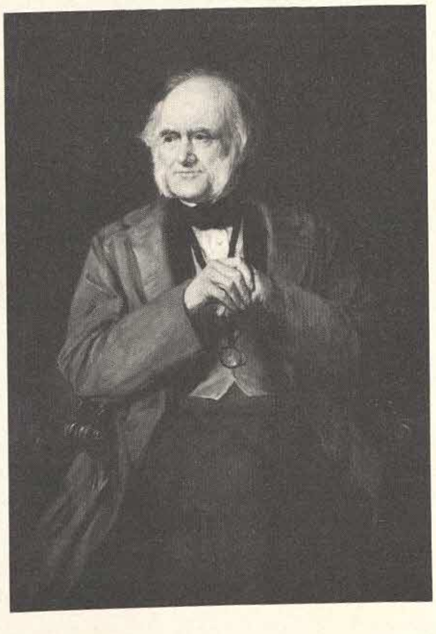
The French biologist André Lwoff shared the 1965 Nobel Prize in medicine or physiology for his discoveries concerning regulatory activities inside cells. The other co-winners were the French scientists François Jacob and Jacques Monod. (*See* François Jacob; Jacques Monod.)

Lwoff was born in the Allier Department of central France to Russian-Polish parents. In 1921 he earned a bachelor's degree in natural science and in 1927 a medical degree and a doctorate in natural science. He did research at the Pasteur Institute of Paris and later became professor of microbiology at the Sorbonne in Paris. For his work with the underground during World War II, he received the Medal of the Resistance and also was made an officer in the French Legion of Honor.

LYELL, SIR CHARLES (1797–1875)

The British geologist Sir Charles Lyell established and popularized, in the mid-nineteenth century, principles of geology that have been generally accepted ever since. In his time—as in that of James Hutton, who had founded geology as an organized science a generation earlier—the prevailing opinion among geologists was that worldwide catastrophes underlie geological history. When Lyell became acquainted with Hutton's views, he saw that they coincided with his own and then devoted himself to proving the truth of what came to be known as uniformitarianism. This doctrine holds that geological history is a matter of ordinary processes, such as heat and erosion, and that the same processes that have always acted will continue to act in a uniform way. Lyell presented this fundamental principle so forcefully that it became the accepted view.

Sir Charles Lyell



Lyell, the son of Charles Lyell, an accomplished botanist, was born on the family estate at Kinnordy, Forfarshire, Scotland; but the family moved to Hampshire, England, when he was a boy. In 1816 he entered Exeter College, Oxford, where the lectures of William Buckland attracted him to geology. His interest grew as he made geological tours of England, Scotland, and continental Europe. In 1819 he began to study law, which he practiced for a time, but in 1827 he finally abandoned it for geology.

On one of his frequent tours of Europe, Lyell was studying the marine remains of the Italian Tertiary strata when he arrived at the idea of dividing the geological system into three or four groups according to the proportion of recent to extinct species of shells. To these groups he gave the names that were later adopted universally: Eocene, Miocene, and Pliocene.

His greatest work, *The Principles of Geology*, was published in three volumes between 1830 and 1833. From then until 1876, there were twelve editions published, each forming a complete history of the progress of geology since the previous edition. *Elements of Geology* was published in 1838 and went through six editions in Lyell's lifetime. In his third major work, *The Antiquity of Man* (1863), Lyell stated the arguments for man's early appearance, basing them on flint implements discovered in post-Pliocene strata, and supported the origin of species theory propounded by Charles Darwin, the most eminent of his scientific associates—it was Lyell who helped Darwin conclude that the succession of life is the result of uniformitarian evolution. Among Lyell's papers and books are accounts of his travels in North America in 1841 and 1845.

At the age of twenty-two he was already a member of the Linnean and Geological societies, and in 1826 he was elected a fellow of the Royal Society. Lyell was twice president of the Geological Society and in 1866 was the recipient of its Wollaston Medal. The Royal Society awarded him the Royal Medal in 1834 and the Copley Medal in 1858. He was knighted in 1848 and made a baronet in 1864. Lyell bequeathed the means for establishing the Lyell Medal to be awarded annually, or from time to time, by the council of the Geological Society.

LYNEN, FEODOR (1911–)

The German biochemist Feodor Lynen shared the 1964 Nobel Prize in medicine or physiology with Konrad Bloch, a German-American biochemist, for research into the metabolism of cholesterol and fatty acids. The two scientists worked independently; publication of their findings made them aware of their common goal. Their work was somewhat complementary, however, for Lynen was mainly concerned with fatty acids, while Bloch concentrated on sterols. In making the award, the Nobel committee pointed out that any remedy for the circulatory ailments that are accompanied by disturbed fat metabolism would derive from the work done by Lynen and Bloch. Both sought to discover how a cell changes simple chemical compounds into complex molecules of sterols and lipids, or fats.

Lynen was the first to isolate activated acetate, from which both cholesterol and fatty acids are formed, and, together with his colleagues, discovered a group of enzymes that enable the body to produce and consume fatty acids. He found that biotin, a B-complex vitamin, is necessary for the production of fatty acids and explained the pathway of biosynthesis of compounds, including cholesterol, squalene, terpenes, and natural rubber.

Lynen was born in Munich, Germany, where his father was professor of engineering at the Technische Hochschule. Young Lynen was educated as a chemist at the University of Munich, earning his doctorate in 1937, and married the daughter of one of his teachers, Heinrich Wieland, also a Nobel laureate. In 1941 Lynen qualified as a university lecturer at Munich, in 1947 he became professor of biochemistry, and in 1954 he was appointed director of the Max Planck Institute of Biochemistry in Munich. He was elected a foreign associate of the U.S. National Academy of Sciences in 1962.

LYSENKO, TROFIM DENISOVICH
(1898–)

A scientist who won fame because of his errors rather than his accomplishments was the Soviet biologist Trofim Denisovich Lysenko. He wrongly believed that acquired characteristics in plants can be passed on to the next generation of plants. In spite of evidence to the contrary, Lysenko's views were supported by the Soviet dictator Joseph Stalin, with disastrous results to Soviet agriculture.

Lysenko was born at Karlovka in the Ukraine and graduated from the Poltava School of Horticulture in 1921 and from the Kiev Institute of Agriculture in 1925. He rejected orthodox genetics as established by such men as G. J. Mendel and concentrated on practical work in plant breeding similar to that done by Luther Burbank. Actually, his theories were a form of Lamarckism. His major premise in agriculture was the unity of the plant with its environment. He believed that he could direct changes in heredity by controlling environment in such a way that wheat plants would produce rye seeds. He also worked with plant grafting and the breeding of grafted plants. By his method of vernalization, winter seed was sown as spring seed, since its germination had been retarded by freezing.

Even though his work lacked a rigorous statistical basis, Lysenko worded his arguments in such a way that they fit the political thinking of the 1930s in the Soviet Union. He promised higher crop yields than was possible and gave more hope for the future than other biologists, and so with the support of Joseph Stalin he became the leading agronomist in the Soviet Union. Exponents of other theories of genetics were not allowed to voice their opposition to Lysenko, and many geneticists were arrested and probably executed; at any rate, they died under mysterious circumstances.

As director of the Institute of Genetics of the Academy of Sciences of the U.S.S.R., Lysenko was the leader of Soviet biology. In 1940 he also became president of the V. I. Lenin All-Union Academy of Agricultural Sciences. He was awarded the Order of Lenin in 1948 and won the Stalin Prize for his book *Agrobiology* in 1949.

After Stalin's death in 1953, criticism of Lysenko's policies and theories was permitted, and he gradually fell into disfavor. In 1965 he was removed as director of the Institute of Genetics, and efforts were made to restore the orthodox theory of genetics in the Soviet Union's scientific community.

MacLEOD, JOHN JAMES RICKARD
(1876–1935)

The British physiologist John J. R. MacLeod, whose outstanding work involved the control of carbohydrate metabolism in the animal body, was cowinner of the 1923 Nobel Prize in physiology or medicine. He and F. G. Banting shared the award for isolating insulin. (*See* Sir Frederick Grant Banting.)

MacLeod, the son of a clergyman, was born near Dunkeld, Scotland, and educated at Marischal College, Aberdeen, and Leipzig University in Germany. From 1899 to 1902 he was successively demonstrator in physiology and lecturer in biochemistry at the London Hospital. In 1903 he went to Western Reserve University, Cleveland, Ohio, where he became professor of physiology. He remained there until 1918, later becoming professor of physiology, director of the physiological laboratory, and associate dean of the faculty of medicine at the University of Toronto, Ontario, Canada.

It was in MacLeod's laboratory at Toronto that Banting and C. H. Best succeeded in isolating insulin from the pancreas of experimental animals. MacLeod had been interested in diabetes mellitus long before insulin was isolated in 1921. By then the control of human diabetes by regulating sugar intake was well advanced, but severe cases were fatal. Banting divided his portion of the Nobel Prize with Best, and MacLeod shared his with a young chemist, J. B. Collip, who had helped purify the extract so that it would be usable by diabetic patients.

Besides carbohydrate metabolism, MacLeod investigated purine bases, tuberculosis bacteria, carbamates, electric shock, and air sickness. An exceptional teacher and director of research, he trained many successful scientists in his laboratories. From 1901 to 1903 he had held the Mackinnon Research Scholarship of the Royal Society of London.

Among his publications are *Practical Physiology* (1903); *Recent Advances in Physiology*, edited by Leonard Hill (1905); *Diabetes, Its Physiological Pathology* (1913); *Fundamentals of Physiology* (1916); *Physiology in Modern Medicine* (ninth edition, 1941); and many scientific papers.

McCORMICK, CYRUS HALL (1809–1884)

The mechanical reaper was invented by Cyrus Hall McCormick. He was born on a farm in Rockbridge County, Virginia, the eldest son of farmer and inventor Robert McCormick. Since his help was needed on the farm for most of the year, he attended school only during the winter months. The family farm was equipped with a foundry and a workshop, where the father had invented a hemp break and also experimented with a reaper but with no success. Cyrus took up the problem of the reaper, made a model, and demonstrated it for the first time near Steele's Tavern, Virginia, in July 1831—at the age of twenty-two.

Some reaper inventions had already been patented in the United States, and a reaper had been invented in Scotland in 1826. McCormick's first reaper, how-

Cyrus Hall McCormick

ever, employed a reel to pull the grain to the cutting blades and featured a platform for collecting the grain and a divider for keeping the grain to be cut from the grain to be left in the field. The principles used in McCormick's first reaper were essential to all grain-cutting machines thereafter.

He obtained a patent for his reaper in 1834 and sold his first two machines in Virginia in 1840. He continued making improvements on his original invention, however, and took out a second patent in 1845 and a third patent in 1847.

Interested in making and selling reapers and other farm machinery on a large-scale basis, McCormick went to Chicago, Illinois, where in 1846 he sold a half interest in the reaper to the mayor, William Ogden, for $25,000. By 1847 McCormick had enough capital to open a factory in Chicago, and by 1849 he was successful enough to buy back Ogden's half interest. His brothers Leander and William were then admitted as partners.

In 1858 McCormick married Nettie Fowler, who became a close consultant in the business. After his death she assumed control of the company, thereby being the first woman to head a major U.S. business. In 1902 the McCormick Harvesting Machine Company joined with a number of other companies, including Deering Harvester, to become the International Harvester Company.

McCormick's first reaper incorporated principles that were basic in all grain-cutting machines that followed it, but he continued to make improvements.

This new company in the field of agricultural machinery was headed by McCormick's son Cyrus, Jr.

McMILLAN, EDWIN MATTISON (1907–)

The work of the U.S. physicist Edwin Mattison McMillan contributed to a new understanding of the structure of matter and to the discovery of antimatter. He developed a theory that made possible the construction of high-energy accelerators, and he was also the codiscoverer of two transuranium elements, neptunium and plutonium. For his work on transuranium elements he shared the 1951 Nobel Prize in chemistry with Glenn Seaborg. (*See* Glenn Theodore Seaborg.)

McMillan, whose father was a physician, was born at Redondo Beach, California, and studied at the California Institute of Technology, Pasadena, and at Princeton University, from which he received his doctorate in 1932. He then became a National Research Council fellow at the University of California at Berkeley, where in 1935 he joined the physics faculty and began working on cyclotrons. During World War II he interrupted his career at the university to work on radar and sonar and was also involved with the development of the atomic bomb, working at Los Alamos, New Mexico. In 1946 he was appointed a full professor at the University of California, becoming associate director of its radiation laboratory in 1954 and director in 1958.

Working with Philip H. Abelson, in 1940 McMillan discovered the element corresponding to atomic number 93, the first transuranium element, neptunium. This quickly led to the discovery of plutonium, the transuranium element corresponding to atomic number 94. The work with transuranium elements was then carried on and extended by Seaborg.

McMillan's greatest contribution to high-energy physics was his advancement of the theory of phase stability and the subsequent development of the synchotron, a cyclotron capable of compensating for the increase in the mass of particles traveling at high velocity. This resulted in an increase in the energy that could be given to charged particles and made possible the discovery of antimatter.

The 1963 Atoms for Peace Award was presented to McMillan for his development of the theory that led to synchotrons. He shared the award with the Soviet scientist Vladimir I. Veksler, who had made a similar discovery at approximately the same time. McMillan was elected to the National Academy of Sciences in 1947.

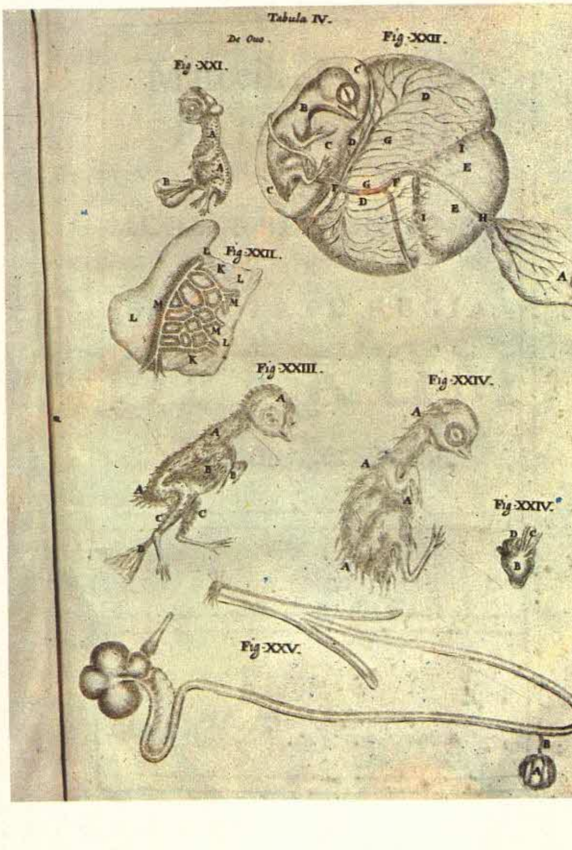
MALPIGHI, MARCELLO (1628–1694)

Through his work in microscopy the Italian anatomist Marcello Malpighi became known as the founder of microscopic anatomy. Galileo had recently started using the telescope for astronomical observations and had thus literally found a whole universe waiting to be discovered; all he had to do was to point his telescope each evening on a new section of the celestial sphere. Malpighi did the same with the microscope: he turned it on the biological world, about which almost nothing was known, and so became a trailblazer in comparative anatomy, histology, embryology, and plant anatomy.

Malpighi was born at Crevalcore, Emilia, Italy, the eldest of eight children. Having early lost his parents, he had to face considerable financial difficulties;

Marcello Malpighi

One of the best accounts of the development of the chick was that given by Marcello Malpighi in *Observationes de ovo incubato*, which was included in his *Anatomia platarum* (1672).


Tabula IV.
De Ovo.
Fig. XXII.
Fig. XXI.
Fig. XXII.
Fig. XXIII.
Fig. XXIV.
Fig. XXIV.*
Fig. XXV.

nevertheless, he received an excellent education as a child and then enrolled at the University of Bologna, where he graduated in medicine in 1653 and began teaching three years later.

His early fame led the Grand Duke of Tuscany to invite him in 1656 to Pisa, Galileo's native city and at that time the center of experimental studies and the seat of the famous Academy of Sciences. It was a highly suitable environment for Malpighi's research. In 1659, however, he left the faculty of theoretical medicine at Pisa and returned to Bologna, and in 1662 he moved to Messina.

Embittered by his opponents' repeated attacks, Malpighi went back to Bologna in 1666, passing the next twenty-five years in his villa at Cortivella dedicated to study and to family life. His marriage to the sister of a beloved teacher was happy, though there were no children and despite the fact that the disputes with his adversaries had moved from a scientific to a personal level. At Bologna he met the future Pope Innocent XII, then but a legate, who valued not only Malpighi's outstanding ability in the diagnostic and therapeutic fields but also his moral qualities. When he became pope, Innocent XII invited the great scientist to be his official physician. Malpighi's health was already poor, and he accepted the position reluctantly, since it meant he had to leave the city that he still loved despite the wrongs and the pain he had endured there. He had lived in the city of Rome but three years when he died.

Among the greatest of Malpighi's many experiments was his determination, in 1660–1661, of the structure of the lung. Until that time the nature of even such an easily analyzed organ as the lung was completely unknown. Malpighi examined it under the microscope, however, and noted that it was formed of membranous cavities filled with air and that the blood flowed through a network of vessels over the lung. These observations led him to the discovery of the capillaries, which had been the missing link in William Harvey's theory of blood circulation advanced a generation earlier.

Having observed the circulation of blood, Malpighi then turned his attention to the study of blood itself. On examining it under the microscope, he found that it contained strange bodies, which at first he thought were clots of coagulated blood and then fat particles. These were actually red blood corpuscles, but at the time he did not know their significance.

Malpighi also investigated other parts of the human body closely under the microscope. He discovered papillae at the back of the tongue and correctly assumed that they were of vital importance to the sense of taste; he proved that a sheath of connective tissue, which today is called the Malpighian capsule, encloses the blood vessels entering the spleen; he discovered in the spleen the lymph nodes now known as the Malpighian follicles; he brought to light the structure of the kidneys, describing their Malpighian corpuscles and surrounding capsule; and he revealed the germinative layer of the skin —where the regenerative cells develop— also called the Malpighian layer.

In the course of his studies of animal microscopic anatomy, Malpighi investigated the formation of chicken embryos, described the respiratory vessels of insects (the Malpighian tubules), and wrote the first full account of the structure of an insect. He also devoted much of his time to the study of plants. One of his first discoveries was that vegetable tissue, as the Englishman Robert Hooke had also realized, is composed of many small sacs lying close to one another, which Malpighi called utricles.

In his research Malpighi used quite simple microscopes, some of which are preserved in London, where he was held in high esteem by his English colleagues of the Royal Society. Many of his more important writings were published in the society's papers.

MANN. See Gell-Mann, Murray.

MANNUCCI, TEOBALDO. See Manuzio, Aldo.

MANUTIUS, ALDUS. See Manuzio, Aldo.

MANUZIO, ALDO (1449–1515)

The fifteenth century was an auspicious time for the invention and spread of printing in Europe. There existed a ready market for books among the university students and the members of the rising middle class, for reading was no longer a clerical monopoly; there were means for marketing the books; and there was an abundant supply of paper. Printing was invented in 1440 in Germany and from there spread to, among other places, Italy in 1464. The first texts, generally treating questions of religion or chivalry, did not find favor with the bibliophiles, who preferred their illuminated manuscripts; but the Italian scholar Aldo Manuzio decided that the press could be valuable not only as a means of cultural diffusion but also as an aesthetic pleasure in itself and so became a master printer and founder of the world-famous Aldine Press.

Aldo Manuzio

Manuzio was born at Bassiano, Valletri, Italy. He studied first at Rome with a tutor and then with the most able masters of the time. In 1471 he moved to Ferrara, where he taught in the public schools until he was offered the post of private tutor to Alberto and Lionello, the sons of the Prince of Carpi. For their use Manuzio wrote a Latin grammar and a little book in Greek. After eight years in the Carpi household, he abandoned his comforts and security in order to go to Venice to fulfill his ambition in bookmaking.

Manuzio's press was established in about 1490, and Manuzio set to work with a will to put his ideas into practice. He not only gathered together expert compositors but also, having once collected the texts he intended to publish, submitted his copy to critical revision. His first-published scholarly texts helped him enter the circle of Venetian scholars and made his name known to other printers. Together with some of his friends he founded an academy in order to produce accurate translations of the Greek classics. Manuzio was not so learned as some of the academicians, but he made use of them to publish the best possible texts. It was the first instance of collaboration between intellectuals and publishers.

He had close ties of friendship with another publisher, Andrea Torresani di Asola, with whom he began publishing, at first intermittently, later regularly, until the arrangement became a sort of family company. In 1505 he married his partner's daughter Maria, and they had five children. The printing house went through alternate periods of prosperity and crisis, caused both by commercial problems and political events. Among the latter was the war waged against Venice by the League of Cambrai, which forced Manuzio to flee with his family—to Ferrara in 1509 and to Ravenna in 1512. He then returned to Venice and took up his activities again until his death three years later.

In Manuzio's workshop Johann Gutenberg's primitive printing became a noble art, and the innovations introduced by Manuzio contributed to the spread of the printed word. In considering his tremendous output it is important to remember not only the works he printed, of which he himself published three catalogs, but also his original writings, for the most part erudite studies: Latin poetry, some fine translations, a collection of letters, and a good many interesting prefaces to various texts.

From a technical standpoint Manuzio's press contained three principal innovations: the introduction of the Aldine, or cursive, type, which is the inclined type derived from handwriting and now known as italic; the octavo size, which is easily handled and does not require a reading desk; and innovations in methods of binding. His editions—extremely refined in the care of both the text and illustrations, as well as in the paper, inks, and binding—were distinguished by his colophon, the anchor and dolphin, which he took from the reverse of an ancient Roman coin of Emperor Titus. He was so well known abroad, especially in France, that in 1502, in order to combat plagiarism, he requested from the Venetian Senate and Pope Alexander VI special privileges that gave protection similar to that afforded later by copyright.

Manuzio's work did not come to an end with his death, being continued by his brothers-in-law, a son, and a grandson. The son, Paolo, took over the direction of the press in 1533; and in 1540, in protest against the poor quality of some of the editions, he separated from his uncles. In 1561 he was invited by the pope to transfer his printing activities to Rome. The grandson, who was named after his grandfather and is remembered as Aldo Manuzio the Younger, was the last director, from 1561 to 1584, of the Aldine Press. Altogether the three generations published approximately 1,000 editions.

MARCONI, GUGLIELMO (1874–1937)

Unlike many versatile great scientists, the Italian Guglielmo Marconi dedicated himself entirely to radiotelegraphy, which he followed and directed in all phases of its development. For his great invention he shared the 1908 Nobel Prize in physics with the German physicist Karl F. Braun. (*See* Karl Ferdinand Braun.)

Marconi was born in Bologna, Italy, the son of an Italian country gentleman and his Irish wife. He was educated at home by tutors and at the technical school in Leghorn, where he studied physics, including electromagnetic wave technique. In 1894 the family settled on their country estate at Pontecchio, and Marconi started experiments based on the recently published works of Heinrich R. Hertz.

It was the age of telegraphy. The oceans were crossed by cables that made it possible to send news from one continent to another, and special techniques had been developed for their construction and for the sending and receiving of signals. The cables required care, however, and there was always the danger that they might be tampered with or accidently put out of commission.

The possibility of transmitting energy or signals over long distances fascinated many scientists. The idea of wireless telegraphy had led to research on systems of optical telegraphy. A new idea occurred to Marconi: the possibility of using electromagnetic waves. Physicists had shown that they behave like luminous waves, and Marconi decided to utilize them to construct a system similar to that of the optical telegraph. There were considerable difficulties, however. If electromagnetic waves traveled in a straight line, the obstacles that lay in their path between the transmitting stations would have to be overcome, as well as the curvature of the Earth itself. It was also necessary to discover how to modulate the signals to be transmitted.

As a first step in his development of wireless telegraphy, Marconi decided to repeat the experiments of his forerunners, but outside the laboratory, and proceeded to build a number of oscillators and detectors. His first experiment, conducted in the spring of 1895, in which he tried to receive the waves from a distance of a few hundred yards, was a success and showed that Hertzian waves could be transmitted from a distance, though it was not yet known whether they could overcome natural obstacles. This was demonstrated, however, by a second experiment, in which the waves were received on the far side of a hill.

Marconi was then able to lay the foundations for the development of wireless telegraphy; however, before it could be turned into a practical system, he had to make the world realize the importance of his discovery and to find somebody to finance the enterprise. Discouraged by the attitude of the Italian government, he went to England, where he received the support of William Preece, the engineer-in-chief of the post office, who had himself invented a short-distance transmission system. In 1896 Marconi was granted the first patent for wireless telegraphy and soon thereafter succeeded in sending signals across greater and greater distances—up to four miles on Salisbury Plain and to nearly nine miles across the Bristol Channel; in 1899, messages were being sent at distances up to seventy-five miles. Meanwhile, in 1897, he had founded in London the Wireless Telegraph and Signal Company, Limited, which was changed in 1900 to Marconi's Wireless Telegraph Company, Limited, and later developed worldwide affiliations.

There were still some serious misgivings, however, about what effect the Earth's curvature might have on the transmission of radio signals. To prove that the radio waves would follow the curve of the Earth instead of radiating straight outward, Marconi made preparations to send radio signals from Poldhu in Cornwall, England, to Saint John's, Newfoundland, and succeeded on December 12, 1901, which marks the date of the invention of radio.

Other devices invented by Marconi for the improvement of communications included the magnetic detector, in 1902; the horizontal directional aerial, in 1905; and the timed-spark system for generating continuous waves, in 1912. Four years later he began experimenting with shortwaves to create a beam system for wartime use. He continued with this research after the war, too; and in 1923, aboard the yacht *Elettra*, he carried out a series of shortwave transmissions, thereby helping develop shortwave wireless communication, which today forms the basis of nearly all long-distance radio communication.

Marconi was the recipient of many honors. In addition to the Nobel Prize, he was awarded the Albert Medal of the Royal Society of Arts and the Franklin

Guglielmo Marconi

and John Fritz medals of the United States (1909); appointed an honorary Grand Cross of the Victorian Order (1914); made a delegate to the Paris Peace Conference (1919); created a marchese and appointed to the Italian Senate (1929); and elected president of the Royal Italian Academy (1930). On his death he was given a state funeral by the Italian government.

MARTIN, ARCHER JOHN PORTER

(1910–)

The British biochemist Archer Martin helped design an important analytical tool that found wide application in biochemical research. Along with Richard Synge he devised a technique known as partition chromatography and shared with him the 1952 Nobel Prize in chemistry. (*See* Richard Laurence Millington Synge.)

Partition chromatography was developed as a method for studying protein molecules. It accomplished the partition of a substance between two liquids by a very simple technique: an amino acid solution was allowed to dry on porous filter paper; this was then dipped into a solvent, which crept up the paper by capillary action; when the creeping solvent passed the dried solution, the various amino acids would creep up with the solvent at varying rates, depending on their solubility, and thus in the end be separated. By this process Martin was able to isolate the various amino acids in a protein substance and measure their amounts. Partition chromatography was later used to discover the order in which amino acids occur in insulin, to test the purity of antibiotics and other pharmaceutical products, and, coupled with isotopic tracers, to analyze photosynthesis and metabolism. In 1953 Martin also developed gas chromatography for separating gases.

Martin was born in London, England, and educated at Cambridge University. After receiving his doctorate in 1936, he worked for two more years at the Dunn Nutritional Laboratory, where he had been doing research on vitamin E since 1933. From 1938 to 1946 he studied the felting of wool at the Wool Industries Research Association and then became head of the biochemistry division of the research department of Boots Pure Drug Company. In 1948 he joined the staff of the Medical Research Council, working at the Lister Institute and later at the National Institute for Medical Research. He was elected a fellow of the Royal Society in 1950 and became director of the Abbotsbury Laboratories, Limited, in 1959.

MAURY, MATTHEW FONTAINE

(1806–1873)

The researches of Matthew Fontaine Maury, U.S. naval officer and hydrographer, resulted in lasting benefits to navigation and meteorology. He received international recognition for teaching ship captains how to shorten ocean voyages by taking advantage of the currents.

Maury was born in Spotsylvania County, Virginia. He entered the navy as a midshipman in 1825 and during a four-year cruise circumnavigated the world on the *Vincennes*. A stagecoach accident in 1839 left him lame and unqualified for active duty; and two years later he was placed in charge of the Depot of Charts and Instruments, which developed into the U.S. Naval Observatory and Hydrographic Office.

Maury sought to obtain information about the winds and currents by having captains of vessels make entries in specially prepared logbooks that he had distributed to them. This pointed out the necessity for combined action on the part of maritime nations in regard to ocean meteorology. In 1853 he initiated an international congress at Brussels, Belgium, at which a worldwide system of record keeping was approved. With the accumulation of data that followed the congress, he was able to revise wind and current charts for the Atlantic and Pacific oceans and to draw one for the Indian Ocean.

When the American Civil War erupted in 1861, Maury, who had been elevated to the rank of commander in 1855, sided with his native South and was put in charge of its coast, harbor, and river defenses. He invented an electric torpedo for harbor defense and went on missions to England for supplies. After the war he went into voluntary exile in Mexico. As imperial commissioner of immigration for Emperor Maximilian, he attempted to found a Virginia colony in Mexico; but the idea was abandoned in 1866, and Maury settled in England. While there he was presented with a testimonial raised by public subscription and was awarded a doctorate of laws by Cambridge University. In 1868 he returned to the United States and accepted the professorship of meteorology at the Virginia Military Institute. Maury was also acclaimed for his advocacy of the transatlantic cable, and it was he who gave the Gulf Stream the classical description "river in the ocean."

Among his published works are *Treatise on Navigation* (1836), *Wind and Current Chart of the North Atlantic* (1847), *Letters on the American and Atlantic Slopes of South America* (1853), *Letter Concerning Lanes for Steamers Crossing the Atlantic* (1855), *Physical Geography of the Sea* (1855), *Physical Geography* (1864), *Manual of Geography* (1871), and papers that he contributed to the *Astronomical Observations* of the U.S. Naval Observatory.

Maury Hall at the U.S. Naval Academy at Annapolis, Maryland, is named in his honor. He was elected to the Hall of Fame for Great Americans in 1930.

MAXWELL, JAMES CLERK (1831–1879)

In his relatively short lifetime the Scottish physicist James Clerk Maxwell made a number of valuable contributions to such scientific studies as astronomy and theoretical physics. His greatest achievement, however, was the translation of Michael Faraday's work on magnetic lines of force into mathematical form, thereby creating the electromagnetic theory.

Maxwell's research on electromagnetism took place from 1864 to 1873; and his famous published work on the subject, *Treatise on Electricity and Magnetism*, appeared in the latter year. To explain Faraday's notions of the field and lines of force, Maxwell devised a system incorporating what he called *ether*, an imaginary medium, through which all electric and magnetic waves were propagated; and to express the continuous na

From 1860 to 1865 James Maxwell taught phy

James Maxwell

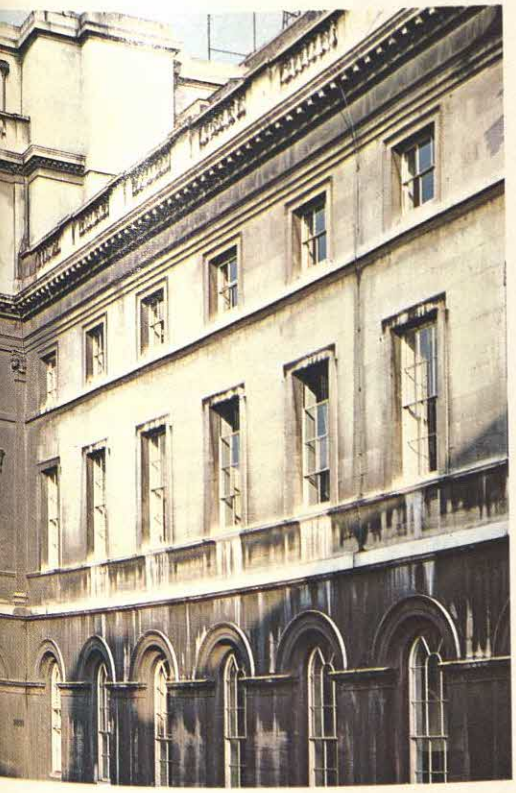
ture of electric and magnetic fields and to show that changes in one produce changes in the other, he developed two sets of symmetrical equations.

In connection with this work Maxwell came to the conclusion that light is a form of electromagnetic radiation. Finding that an oscillating electric charge produces an electromagnetic field radiating outward from its source at a constant speed close to that of light, he concluded that light is also produced by a similar charge. His understanding of the properties of electromagnetic waves led to the discovery made by Heinrich Hertz of radio waves.

Early in his career Maxwell studied color perception and investigated color blindness. He invented a device called the Maxwell disk, and later some of his observations proved useful in methods of color photography. For this work he was awarded the Rumford Medal of the Royal Society.

In the field of astronomy Maxwell took up the problem of the composition of the rings of Saturn and concluded that they are not solid but are composed of myriads of small particles, giving the appearance of a solid and continuous band. His paper on Saturn's rings won him the Adams Prize in 1859.

ics and astronomy at King's College, London.



Another of Maxwell's major scientific contributions was his development of the kinetic theory of gases. He developed a model, incorporating the idea of elasticity, that made it possible to quantitatively account for the diffusion, viscosity, and heat conduction of a gas. Maxwell believed that gas molecules move not only in all directions but also at different speeds. Despite certain flaws in his model, he obtained the correct results; and his laws concerning the kinetic theory of gases have held true to the present day.

Maxwell was born in Edinburgh, Scotland, to a distinguished family. Early in his life he exhibited a talent for scientific pursuits, which earned him the nickname "Daffy" among his classmates. At age fifteen he wrote a paper on a method of producing perfect oval curves, which was read to the Royal Society of Edinburgh; and at age eighteen he submitted two papers to the Royal Society: one on the subject of rolling curves, the other on the equilibrium of elastic solids. He was educated at the University of Edinburgh and at Trinity College, Cambridge, graduating with high honors from the latter in 1854. Two years later he was appointed professor of natural philosophy at Marischal College, Aberdeen, and in 1860 he became professor of physics and astronomy at King's College, London. Then in 1865 he retired to his estate in Scotland and carried out his research there; but in 1871 he returned to the academic world as the first professor of experimental physics at Cambridge, where he remained for the rest of his life. While there he supervised the construction of the famous Cavendish Laboratory and edited and published the works of Henry Cavendish on the subject of electricity. Among Maxwell's best-known published works are the two textbooks *Theory of Heat* (1871) and *Matter and Motion* (1876).

MAYER, MARIA GOEPPERT (1906–   )

The German-U.S. nuclear physicist Maria Goeppert Mayer added greatly to knowledge of atomic nuclei. Her work on nuclear shell structure earned her the 1963 Nobel Prize in physics, which she shared with Johannes Jensen and Eugene Wigner. (*See* Johannes Hans Daniel Jensen; Eugene Paul Wigner.)

In 1947 Mayer observed that some nuclei were more stable and richer in isotopes than others. These nuclei had a particular number of neutrons and a corresponding number of protons. To explain the differences in nuclei she proposed that nuclei are made up of protons and neutrons in orbits, or shells, similar to the electron orbits of the outer atom. A major characteristic of the model she suggested was the strong coupling of the spin of the nucleon to the angular momentum of its orbit. Jensen reached a similar conclusion independently at about the same time. At the beginning of her career Mayer's work included the calculation of absorption spectra of organic molecules and the separation of isotopes by chemical means.

Maria Goeppert was born at Kattowitz, Germany (now part of Poland), a descendant of a long line of university professors. In 1930 she obtained her doctorate from the University of Göttingen, where her father was professor of pediatrics. Following her graduation she married Joseph Mayer, a U.S. chemical physicist, and went with him to Johns Hopkins University, Baltimore, Maryland, becoming a U.S. citizen in 1933. In 1939 she joined the faculty of Columbia University, where she worked on the separation of uranium isotopes; in 1945 she went to the University of Chicago's Institute for Nuclear Studies; and in 1960 she was appointed professor of physics at the University of California, San Diego.

She became a member of the U.S. National Academy of Sciences in 1956. With her husband she wrote *Statistical Mechanics* (1940); with Jensen, *Elementary Theory of Nuclear Shell Structure* (1955).

MAYO FAMILY

Several members of the Mayo family were distinguished U.S. physicians and surgeons. Their name is especially known for the clinic that they founded in Rochester, Minnesota.

William Worrall Mayo (1819–1911) was born near Manchester, England, and emigrated to the United States in 1845. He received medical degrees from Indiana Medical College in 1850 and the University of Missouri in 1854. After practicing in Lafayette, Indiana, he moved to Rochester, Minnesota, in 1863. When Saint Marys Hospital opened there in 1889, he and his two sons were asked to head the medical staff. After he retired, his two sons carried on the work.

William James Mayo (1861–1939), the older son, was born at Le Sueur, Minnesota, and received his medical degree

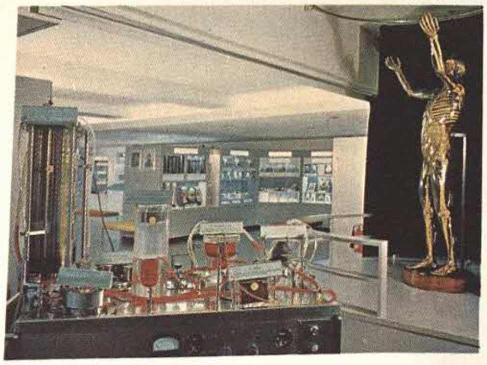
Charles H. and William J. Mayo

in 1883 from the University of Michigan before entering practice with his father. Charles Horace Mayo (1865–1939), the younger son, was born in Rochester, Minnesota, and joined the practice of his father and brother after graduating from the Chicago Medical College in 1889.

The Mayo medical team became well known and began to attract patients from all over the United States. Well read and well traveled, the Mayos introduced the latest medical and surgical techniques into their hospital. William James became a specialist in surgery of the stomach, while Charles Horace developed new procedures in goiter surgery and in neurosurgery.

By the turn of the century the Mayos saw the need to expand their medical facilities and decided to set up a cooperative medical practice in a clinic of their own. They invited a number of associates to join them, hired medical assistants, and in 1914 opened the Mayo Clinic. It was an immediate success, and another building was added in 1928. Today it is still one of the largest and best known private clinics in the world, a voluntary association of hundreds of physicians and specialists.

Visitors to the Mayo Medical Museum in Rochester, Minnesota, learn about the structure and functions of the human body and the efforts being made to combat disease.



The Mayos made a great deal of money in their work—more than they needed or wanted. Even before they started their clinic, the three began making plans to put the money to beneficial use. They invested it, setting up a special trust fund, and in 1915, with $1.5 million, established the Mayo Foundation for Medical Education Research. When the foundation became affiliated with the University of Minnesota Graduate School two years later, the school assumed control of the money. The Mayo brothers retired in 1928 and 1930, respectively; but to ensure that their clinic would continue to operate after their death, they organized the Mayo Properties Association (later the Mayo Association), a charitable and educational corporation that would be self-perpetuating, to control all clinic properties and funds and assume sole ownership.

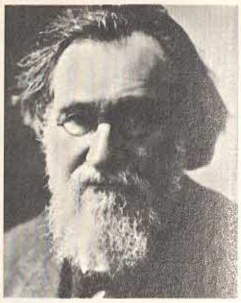
Charles Horace's son Charles William Mayo (1898–1968) was also a surgeon. In addition, he served on the Board of Governors of the Mayo Clinic, on the Board of Regents of the University of Minnesota, and as chairman of the Mayo Association.

MECHNIKOV, ILYA ILICH (1845–1916)

For his accomplishments in the field of immunity the Russian biologist Ilya Mechnikov shared the 1908 Nobel Prize in physiology or medicine with Paul Ehrlich. Mechnikov was the first scientist to emphasize the importance of white blood cells in fighting infection, and by 1892 his views were firmly established. (*See* Paul Ehrlich.)

In experiments with simple transparent invertebrates, Mechnikov observed wandering cells in the mesoderm, which is the equivalent of mammalian connective tissue, and noticed that when a foreign body, such as a wooden splinter, penetrated the animal's ectoderm, the wandering cells surrounded it. He applied these findings to studies of higher animals and discovered that the leukocytes, or white cells, in their blood correspond to the wandering cells in the lower forms and that they digest bacteria. Recognizing their importance as defenses against infection, Mechnikov named them phagocytes, or "eating cells." Although others before him had observed leukocytes while examining inflammations, it was Mechnikov who emphasized their role as phagocytes.

Mechnikov was a native of Ivanoka, Kharkov, in the Ukraine, where his father was an officer of the Imperial Guard. At age seventeen Mechnikov entered Kharkov University but went to Germany two years later for advanced study. Upon his return to Russia in 1867, he became a lecturer in Saint Petersburg (now Leningrad) and later at Odessa. In 1870 he was appointed professor of zoology and comparative anatomy at Odessa; but wishing to devote his time to research, he resigned in 1882 and went to Messina, Italy, where he began his studies of the nature of microbes. In 1888, at the invitation of Louis Pasteur, he joined the Pasteur Institute in Paris, France, and worked there for the rest of his life, succeeding Pasteur as director in 1895.



Ilya Mechnikov

Publications by Mechnikov include *The Comparative Pathology of Inflammation* (1892), *Immunity in Infectious Diseases* (1901), and *The Nature of Man* (1903). He was awarded the Copley Medal of the Royal Society in 1906.

MEDAWAR, PETER BRIAN (1915–)

For proving that acquired immunological tolerance can be produced in the laboratory, Peter Brian Medawar, British biologist, was one of the co-winners of the 1960 Nobel Prize in physiology or medicine. He shared it with Frank Macfarlane Burnet, who had provided the concept behind the experiments by Medawar and his associates. (*See* Sir Frank Macfarlane Burnet.)

Medawar's group showed that inoculating fetal mice with living cells from a future donor made them tolerant to skin grafts from the donor in later life. Burnet had predicted this outcome, theorizing that in some way during embryonic life, cells learn to distinguish between their own tissue substances and foreign substances. Thus, if substances that would be antigenic to an adult were injected during embryonic life, they should inhibit the development of an antibody response. It was hoped that Medawar's work would help solve the problem of grafting foreign tissues and that it would deeply influence the study of immunity in general. Later, Medawar and his associates demonstrated that the substances that excite transplantation immunity can be extracted from cells.

Medawar was born in Rio de Janeiro, Brazil, of British parentage, and educated at Magdalen College, Oxford University, England, from which he graduated in 1939 and received his doctorate in 1948. During World War II he devised a solution, made basically of fibrinogen (the blood-clotting protein in blood plasma), for holding nerve grafts and reuniting severed nerves. In 1947 he was appointed Mason Professor of Zoology at the University of Birmingham, in 1951 he became Jodrell Professor of Zoology and Comparative Anatomy at University College, London, and in 1962 he was named director of the National Institute for Medical Research in London.

Medawar's publications include *The Uniqueness of the Individual* (1957) and *Reith Lectures on the Future of Man* (1960). He was elected a fellow of the Royal Society of London in 1949 and received its Royal Medal in 1959.

MEITNER, LISE (1878–1968)

The pioneer work of Austrian-Swedish physicist Lise Meitner in nuclear physics was instrumental in bringing about the generation and control of nuclear power. She and her nephew and colleague Otto Frisch were the first scientists to identify and correctly define nuclear fission.

Meitner, a lawyer's daughter, was born in Vienna, Austria. She entered the University of Vienna in 1901 and received her doctorate in 1906. The following year she went to Berlin, Germany, where she attended the lectures of the great physicist Max Planck, also serving as his assistant for a time, and worked with the physical chemist Otto Hahn. In 1913 she became a member of the Kaiser Wilhelm Institute for Chemistry, being made head of its physics section and joint director with Hahn four years later, and in 1926 was appointed extraordinary professor of physics at the University of Berlin. When Nazi Germany invaded her native Austria in 1938, she fled to Sweden, where she resumed her research, first at the Nobel Institute for Physics in Stockholm and later at the Atomic Energy Association. She visited the United States following World War II but returned to Sweden, where she became a citizen in 1949. In 1960 she retired to Cambridge, England.

During their thirty-year collaboration Meitner and Hahn identified a new element, protactinium, as well as other radioactive substances. Their work with neutrons began in 1932 at the Kaiser Wilhelm Institute, and a few years later they were conducting experiments on the effect of neutron bombardment on uranium. When Meitner left Germany, Hahn continued these experiments with Fritz Strassmann and soon reported the production of much lighter elements, including barium. On hearing this, Meitner and Frisch concluded that the isotope of barium resulted from a process that they named nuclear fission and that the unstable uranium nucleus had split up after bombardment, forming the nuclei of the isotopes of barium and other elements.

Lise Meitner

Meitner belonged to many scientific academies and received important professional honors. In 1955 she was elected to the Royal Society and in 1960 to the American Academy of Arts and Sciences. She received the Enrico Fermi Award jointly with Hahn and Strassmann in 1960.

MENDEL, GREGOR JOHANN (1822–1884)

A man whose work became one of the greatest single influences on modern biology was the Austrian priest and botanist Gregor Johann Mendel. His world-renowned research on peas, conducted in a monastery garden, formed the very basis of genetic science and modern theories of heredity. Like Darwin's theory of evolution, Mendel's laws of inheritance revolutionized the study of biology.

He was born Johann Mendel to peasant parents at Heinzendorf, Austrian Silesia (now Czechoslovakia). After studying for two years at the Philosophical Institute at Olmütz, he ran out of funds and in 1843 joined the Augustinian order at Brünn (now Brno, Czechoslovakia), taking the name Gregor. In 1847 he was ordained a priest.

Since it was the practice at the time for the Augustinians to supply the local schools with teachers, in 1849 Mendel was made a deputy teacher of Greek and mathematics in a high school at what was then Znaim. In 1851 the order sent him to the University of Vienna, where he studied biology, chemistry, mathematics, and physics until 1853. Although he made several attempts, he was never able to pass the teacher's qualifying examination, probably because of a basic fear of tests. In 1854 he became a teacher of natural science at the technical high school in Brünn and kept this position until 1868, when he was elected abbot of the monastery.

Mendel's great experiment with garden peas was conducted over a period of eight years, beginning in 1857. To be sure of the parentage of the new plants, he was careful to self-pollinate the parent plants. He made observations of seven separate characteristics and noted that dwarf pea seeds produced dwarf pea plants, that seeds from tall plants produced a mixture of dwarf and tall plants, and that the ratio of tall plants to dwarf plants was three to one. When he crossed purebred tall plants with dwarf plants, the resulting hybrid plants were all tall; and when these, in turn, were self-pollinated, the next generation of plants was one-fourth purebred dwarf plants, one-fourth purebred tall plants, and one-half hybrids.

In his experiments on the transmission of characteristics in the pea plant, Gregor Mendel took precise care in studying the green and yellow seeds and their resulting combinations.

From these experiments Mendel conceived the idea of dominant and recessive characteristics, tall being dominant, and dwarf recessive.

Fortunately, he was interested in mathematics, as well as botany, and theorized that characteristics were transmitted in paired units, one unit from the male and one unit from the female. These units are now known as genes. He symbolized the paired units as *AA* (pure, dominant), *aa* (pure, recessive), and *Aa* (hybrid). Further, and perhaps most importantly, he worked out the statistical laws by which the units, or genes, combine.

Gregor Mendel

In studying the seven different characteristics in the pea plants, such as color, height, and seed shape, Mendel found that each characteristic was passed on to the next generation independently of the other characteristics and that the various characteristics in the parent plants recombined randomly in the new plants. From all of these observations he formulated two great laws—the law of segregation and the law of independent assortment of characteristics.

Anxious for other scientists to follow up on his work, Mendel, at meetings of the Brünn Natural Science Society in 1865, read papers describing his experiments and theories. These were published in the society's transactions the following year but aroused little or no interest. Mendel also contacted a prominent botanist at the University of Munich, but he, too, was something less than enthusiastic and suggested that Mendel try his experiments on hawkweeds. Because of their reproductive peculiarities, however, these were unsuitable for Mendel's type of research and presented him with insurmountable problems.

After becoming an abbot, Mendel had less time for scientific pursuits. In addition to his administrative duties, he was involved in a contest with the Austrian government over the issue of taxation on religious institutions. Disappointed and disillusioned by the coolness of the scientific community toward his work, Mendel died without even suspecting the impact that his important discoveries would have on the world of science in the twentieth century.

MENDELEEFF, DMITRY IVANOVICH
(1834–1907)

The nineteenth-century Russian chemist Dmitry Mendeleeff tabulated, according to their atomic weights, all the chemical elements then known. This periodic table of the elements unified a tremendous amount of information and pointed the way to new discoveries. Several chemists had recognized numerical sequences among the atomic weights of some elements and had noted other relationships, but Mendeleeff worked out a system that not only classified the elements but also gave rise to the generalization known as the periodic law, which could be relied upon to predict undiscovered facts.

Mendeleeff was born at Tobolsk, Siberia, the son of the local high-school principal. He took teacher's training at the Pedagogical Institute in Saint Petersburg (now Leningrad) and later studied chemistry, graduating in 1856. After pursuing further learning in France and Germany, he returned to Saint Petersburg, where he became professor of chemistry at the Technological Institute in 1863 and professor of general chemistry at the University of Saint Petersburg in 1866. Following a dispute with the administration, however, he resigned the professorship in 1890, and three years later became director of the Bureau of Weights and Measures, an office he held for the rest of his life.

Preparing to write his great textbook *The Principles of Chemistry*, which he produced between 1868 and 1870—the English edition did not appear until 1905—Mendeleeff sought a system of classifying the sixty-three elements then known. This led to his formulation of the periodic law, which was presented orally to the Russian Chemical Society in 1868 and published the following year. It was translated into German at once and thus came quickly to the attention of scholars in western Europe. Mendeleeff showed that if the elements are arranged in order of their atomic weights, chemically related elements appear at regular intervals. Gaps in his table enabled him to predict the existence of three elements then still unknown and to ascribe definite properties to them and their compounds. Within fifteen years the elements gallium, scandium, and germanium were discovered, bearing out his predictions. Mendeleeff also questioned the assigned atomic weights of certain elements that deviated from the periodic law and was subsequently proved correct.

Dmitry Mendeleeff

His other researches included the investigation of the thermal expansion of liquids, which led him to the discovery that there is a critical point at which liquid and vapor become indistinguishable. He also made studies of petroleum, even going to the United States to study the Pennsylvania oil fields in order to better advise Russia on its development of the ones in Caucasia.

Mendeleeff was elected a foreign member of the Royal Society in 1890. Earlier, in 1882, he had won its Davy Medal, and in 1905 he received its Copley Medal. An element (number 101) discovered in 1955 was named mendelevium in recognition of his contributions to chemistry.

METCHNIKOFF, ÉLIE.
See Mechnikov, Ilya Ilich.

MEYERHOF, OTTO FRITZ (1884–1951)

The work of the German-American physiologist Otto Meyerhof was important to the understanding of the metabolism of muscle cells. He established the relationship between the consumption of oxygen and the production of lactic acid in muscles, and for this he was awarded the 1922 Nobel Prize in physiology or medicine, which he shared with A. V. Hill. (*See* Archibald Vivian Hill.)

Originally, Meyerhof was interested in psychology and psychiatry; however, meeting the biologist Otto H. Warburg inspired him to turn his attention to physiology. His early research was on the mechanism of cellular oxidation, and later he became especially interested in the metabolism of muscle cells. He discovered that glycogen breaks down to form lactic acid in muscles and that when these are at rest, some of the lactic acid is oxidized, making it possible for most of the lactic acid to be reconverted to glycogen.

Meyerhof was born in Hanover, Germany, and studied at the universities of Berlin, Freiburg, Strasbourg, and Heidelberg, receiving his medical degree in 1909 from the last-named institution. In

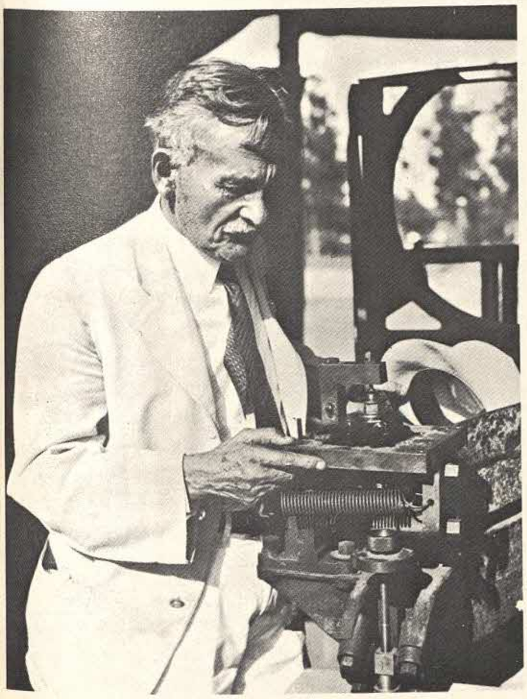
1918 he became professor at the University of Kiel and in 1924 joined the staff of the Kaiser Wilhelm Institute for Biology at Dahlem-Berlin, remaining there until 1929, when he was appointed director of the Kaiser Wilhelm Institute for Medical Research at Heidelberg. Because of the political situation, he was forced to leave Germany in 1938 and continue his work in Paris. Two years later, when Hitler's armies invaded France, Meyerhof fled to the United States, where he obtained a position at the University of Pennsylvania as research professor in the Department of Physiological Chemistry. He became a U.S. citizen in 1948.

MICHELSON, ALBERT ABRAHAM
(1852–1931)

Few men can claim to have contributed to the progress of science with the invention of a single instrument and to have effected with it more measurements than most other scientists put together. Such a man, however, was the U.S. physicist Albert A. Michelson, who with his interferometer made a number of experiments that contributed significantly to the progress of physics. For his spectroscopic and metrological studies he was awarded the 1907 Nobel Prize in physics, the first American so honored.

He was born at Strelno, Prussia, to a young Jewish couple. Two years later the family emigrated to the United States, settling first in New York City, then in California, and finally in Nevada. Michelson graduated from the U.S. Naval Academy, Annapolis, Maryland, in 1873 and taught physics and chemistry there from 1875 to 1879. After a year at the Nautical Almanac office, Washington, D.C., he went to Europe for two years and studied in Berlin and Heidelberg and at the Collège de France and the École Polytechnique in Paris. On his return to the United States he was named professor of physics at the Case School of Applied Science, Cleveland, Ohio; in 1889 he joined the faculty of Clark University, Worcester, Massachusetts; and in 1892 he became professor and the first head of the Department of Physics at the University of Chicago, where he stayed until his retirement, having been appointed its first Distinguished Service Professor in 1925.

Albert Michelson



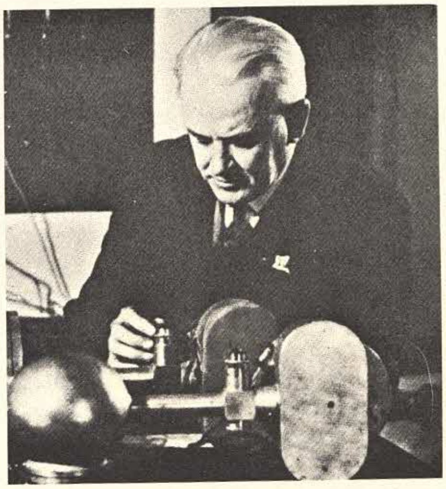
It was during his years at Annapolis that Michelson developed the interest in optics that was to focus his attention and his research activities for the rest of his life on two fundamental points: the determination of the speed of light and the study of optical interference. While in Paris, France, he conceived the idea of the interferometer for discovering the effect of the Earth's motion on the velocity of light. The principle of the instrument was to split a beam of light in two; make the two halves travel at right angles to each other, one in the direction of the Earth's motion, and the other at right angles to it; and then bring the two halves back together again. Since it was believed that the Earth traveled through ether, which was motionless, it was assumed that the beam sent in the direction of the Earth's motion would travel more rapidly than the one sent at right angles to it. The two beams ought, therefore, to fall out of phase and show interference fringes; and by measuring the width of these, it would be possible to find the Earth's exact velocity when compared with ether. Michelson's first experiment with the interferometer, which took place in Hermann von Helmholtz' laboratory in Berlin in 1881, failed to show any interference rings, nor did the famous one he conducted with Edward Morley in 1887. Instead, evidence was presented that light travels at a constant speed in all inertial systems of reference.

Using the interferometer, however, Michelson was able to measure the width of heavenly bodies, notably that of the large satellites of Jupiter and, in 1920, that of the giant star Betelgeuse. His other achievements included the standardization of the meter in terms of the wavelength of cadmium, and near perfect calculations of the velocity of light.

Michelson received many awards, among them the Rumford and Copley medals of the Royal Society, to which he had been elected in 1902, and the Grand Prix at the 1900 Paris Exposition. In 1970 he was elected to the Hall of Fame for Great Americans. His publications include *Velocity of Light* (1902), *Light Waves and Their Uses* (1899; 1903), and *Studies in Optics* (1927).

MILLIKAN, ROBERT ANDREWS
(1868–1953)

In his autobiography the U.S. physicist Robert A. Millikan, recipient of the 1923 Nobel Prize in physics, emphasizes how the most important decisions of his whole life were determined by a series of chance circumstances. He was born in Morrison, Illinois, the son of a Congregational minister of Anglo-Scottish origin, and spent his childhood in Maquoketa, Iowa. After his schooling there, he studied Greek and mathematics at Oberlin College in Ohio and was offered a temporary post as a physics teacher. Although he was not well versed in this field, he accepted the post because the salary was high and his Greek teacher urged him on, with the argument that a good Greek scholar could certainly teach physics as well.



Robert Millikan

Before starting his year's teaching, he spent the summer studying the new subject. He was surprised to discover that "physics teaches itself" and decided then and there to dedicate himself to the new discipline. After teaching for three years, he enrolled in the physics faculty at Columbia University, where he continued his studies in order to obtain a degree. He was helped by Ogden Rood, a professor who not only befriended him but also assisted him in his research on the polarization of the light emitted by an incandescent body. It resulted in such an outstanding thesis that it later was awarded a prize.

Millikan obtained his degree in 1895, but because of the small number of posts available he was unable to get a permanent appointment at Columbia University. Persuaded by a professor there, he set out for Germany, where he attended the universities of Berlin and Göttingen. There were many distinguished teachers of physics in Europe at the time, and Millikan managed to attend many of their courses, though almost penniless, by traveling from city to city on a bicycle.

One day he received a telegram from Professor Albert Michelson—with whom he had studied in Chicago in 1894—inviting him to work as his laboratory assistant, a unique and coveted opportunity. His first years at Chicago (1896–1908) were spent on research to determine the charge carried by an electron, on his courses, and on the preparation of textbooks. He was busy developing a new and improved teaching method based chiefly on research and laboratory experiments, in which he made the students take part directly, first as assistants and then as collaborators.

Millikan found an imaginative solution to the problem of measuring the electrostatic charge of the smallest particle then imaginable: the electron. He built an extremely complicated apparatus by means of which drops of oil nebulized with a common spray could be kept in motionless suspension in the air and then displaced by being charged with one electron at a time. Today the same measurement can be undertaken with an instrument that can be built cheaply by a student, but at that time the apparatus constructed by Millikan was a masterpiece of ingenuity and a complete novelty as far as existing techniques in atomic physics were concerned.

His next contribution was the measuring of the energy contained in a light quantum, by means of the photoelectric effect produced. Millikan was able to demonstrate the validity of the effect theory formulated by Albert Einstein, as well as measure the value of Max Planck's famous constant. It was these fundamental studies that first brought Millikan fame.

He became increasingly involved in his physics research, which was concerned with ever vaster problems: the study of the valence of atoms in the ionization of gases, the determination of the limits of the spectrum of ultraviolet radiation, the properties shown by various elements in the absorption of x-rays, the tension needed to set off an electric discharge in a high vacuum depending on the surface nature of the discharge electrodes, the Brownian movement, and rocket propulsion. His friendship with the astrophysicist George E. Hale led him to undertake spectroscopic studies. During World War I he also studied systems of defensive and offensive weapons for the U.S. Navy and Air Force.

In 1921, after twenty-five years of friendly but independent collaboration with Michelson, Millikan left the chair at Chicago to accept the directorship of the physics laboratory at the California Institute of Technology, Pasadena. This change of research surroundings encouraged him to study cosmic rays, a field in which he became a leading world expert. To study their intensity and powers of penetration, he organized expeditions to the Bolivian Andes, India, and Tasmania.

Among his many awards and honors was the 1913 Comstock Prize of the National Academy of Sciences. From 1922 to 1932 he represented the United States on the League of Nations Committee for Intellectual Cooperation. He also served as chairman of the Board of Directors of the Huntington Library and Art Gallery, San Marino, California.

MINOT, GEORGE RICHARDS
(1885–1950)

In untreated pernicious anemia the red blood corpuscle count declines progressively until the patient dies. For introducing liver diet to control pernicious anemia, George Richards Minot, a U.S. physician, shared the 1934 Nobel Prize in physiology or medicine with his colleague W. P. Murphy and G. H. Whipple, who had discovered that liver stimulates blood production. (*See* William Parry Murphy; George Hoyt Whipple.)

While still a medical student, Minot developed an interest in blood disorders. He became convinced that pernicious anemia might be a dietary deficiency disease resulting from the lack of a vitamin. Because the ailment always was marked by an absence of hydrochloric acid in the stomach secretions, Minot thought that maybe some vitamin was being absorbed in insufficient amounts as a result of digestive malfunction. Whipple's findings about liver led Minot to think that certain kinds of foods might give favorable results in pernicious anemia. He decided to try liver, and in 1924 he and Murphy began feeding patients up to a half pound of liver daily. The highly successful results were reported in a paper published in 1926.

After establishing the success of liver therapy, Minot and his associates continued studies of anemia and nutritional disturbances, demonstrating the effectiveness of certain liver fractions, of which vitamin B_{12} is now known to be the active ingredient. Minot had been right about vitamin deficiency's being at the root of pernicious anemia: stomach secretion fails, and vitamin B_{12} ceases to be assimilated. The daily half pound of liver originally prescribed by Minot and Murphy usually contained enough vitamin B_{12} to force the assimilation of the necessary daily millionth of a gram despite the absence of the stomach factor.

Minot, the son and grandson of physicians, was born in Boston, Massachusetts, and studied medicine at Harvard University, graduating in 1912. After further instruction at Johns Hopkins Hospital, Baltimore, Maryland, he returned to Boston to serve on the staff of the Massachusetts General Hospital. In 1928, after serving at the Huntington Memorial and Peter Bent Brigham hospitals, he was appointed professor of medicine at Harvard and director of the world-renowned Thorndike Memorial Laboratory at Boston City Hospital.

Minot developed severe diabetes in 1921, the same year in which the hormone insulin was isolated by Sir Frederick G. Banting and Charles H. Best. Their achievement made possible the first specific treatment of diabetes, and Minot was among the first patients in Boston to benefit.

MITCHELL, MARIA (1818–1889)

The first woman admitted to membership in the American Academy of Arts and Sciences was Maria Mitchell, a mainly self-taught nineteenth-century astronomer. The recognition followed her discovery of a new comet in 1847.

She was born in Nantucket, Massachusetts, the daughter of an amateur astronomer, whom she assisted in mathematical calculations. A librarian in Nantucket for twenty years, she used her leisure time for reading, as well as for astronomical observations. From 1865 until her retirement in 1888, she served as professor of astronomy and director of the observatory at Vassar College, Poughkeepsie, New York.

Widely honored, she was awarded a gold medal by the king of Denmark for her discovery of a telescopic comet and in 1850 was elected a member of the American Association for the Advancement of Science. After her death a Maria

Mitchell chair in astronomy was endowed at Vassar, and in 1905 she was elected to the Hall of Fame for Great Americans.

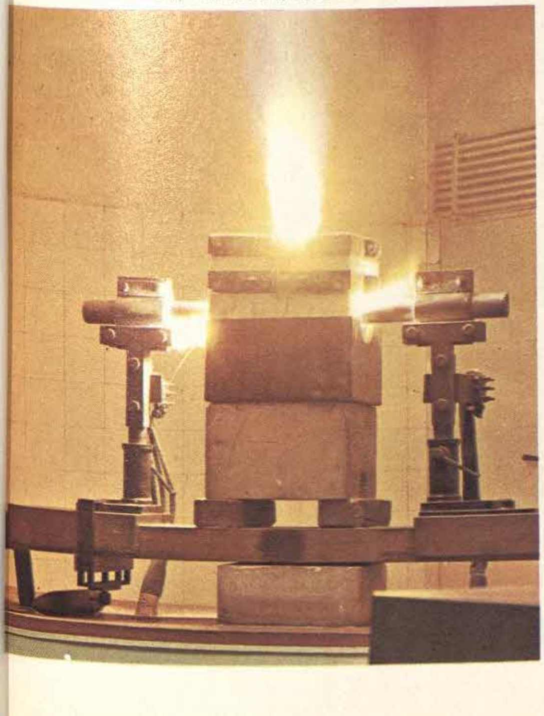
MOISSAN, FERDINAND FRÉDÉRIC HENRI (1852–1907)

For isolating the element fluorine the French chemist Ferdinand Moissan won the 1906 Nobel Prize in chemistry. He is known also for inventing an electric furnace that enabled him to prepare many uncommon metals.

A number of chemists had tried to isolate fluorine; but all had failed, and some had even suffered poisoning. When Moissan decided to undertake the quest, he used apparatus made of platinum, one of the few materials reasonably impervious to corrosion from fluorine. After trying several variations of technique, he passed an electric current through a solution of potassium fluoride in hydrofluoric acid and chilled the solution to 50° C to reduce the activity of fluorine and thus, in 1886, isolated the pale yellow gas that was fluorine, most active of all the elements.

Also significant in Moissan's career was his application of high temperatures obtainable with the electric furnace that he had developed in 1892. In his furnace Moissan prepared samples of such metals as molybdenum, tantalum, vanadium, and uranium long before modern metallurgy made them available commercially. He also experimented with carbon in an attempt to make artificial diamonds, but the temperatures and pressures then available precluded success.

Ferdinand Moissan's electric furnace made it possible to prepare—in a purity never before achieved—many uncommon elements, such as tantalum, vanadium, and uranium.



Moissan was born in Paris. At age eighteen he was apprenticed to an apothecary, but two years later he returned to his studies in order to follow his deep interest in chemistry and in 1879 qualified as a professional pharmacist. Soon after winning international recognition for his work, he was appointed professor of pharmacy at the Paris School of Pharmacy and in 1900 was made professor of inorganic chemistry at the University of Paris.

Ferdinand Moissan

Moissan received many honors. Among them was election to the Royal Society in 1905.

MONET. See Lamarck, Chevalier de.

MONGE, GASPARD (1746–1818)

Modern methods of mechanical drawing are due largely to the work of the French mathematician Gaspard Monge. He developed descriptive geometry, a practical method of applying geometry to the construction arts.

It was a gun emplacement problem on which he was working that led to descriptive geometry. When the practical value of this mathematical method was recognized, it was carefully guarded for many years as a military secret. His other work in geometry, combining synthetic and analytical methods, led to the advancement of projective, analytical, and differential geometry. He also applied calculus to curves and discovered the curves of curvature of a surface.

Monge was born at Beaune, Côte d'Or, France. He was educated at the colleges of the Oratorians at Beaune and Lyons; and by the time he was sixteen years of age, he was teaching physics at the latter place.

While back in Beaune on a visit he drew up a unique plan of the town and presented it to the local authorities as a gift. It was exhibited in the town library, where it was noticed by an officer of engineers, who thereupon recommended Monge for a position at an aristocratic military academy at Mézières. After working as a draftsman and studying at the practical school affiliated with the academy, Monge was appointed professor of mathematics at the academy in 1768 and professor of physics in 1771. He became professor of hydraulics at the Lyceum in Paris in 1780.

A friend of Napoleon, he was appointed minister of the navy in 1792 and carried out operational research on the problem of transporting materials for the construction of fortifications to defend the republic. For his efforts on this project he was rewarded with the title of count of Péluse. He also helped establish the École Polytechnique and in 1795 was appointed its director. When Napoleon fell from power, however, and the Bourbons were restored as the rulers of France, Monge was deprived of all his honors, including his title, and died a poor man.

MONIZ, ANTONIO CAETANO DE ABREU FREIRE EGAS (1874–1955)

In recognition of his pioneer work in brain surgery the Portuguese neurosurgeon Antonio Egas Moniz was awarded a share of the 1949 Nobel Prize in physiology or medicine. Walter R. Hess, a Swiss physiologist, was the co-winner. (*See* Walter Rudolf Hess.)

Moniz developed an operation to relieve certain severe mental diseases by prefrontal leucotomy, also known as prefrontal lobotomy. This procedure involved removing cores of white matter in each frontal lobe (where higher cerebral activity is seated) and transecting the nerves connecting the frontal lobes to the deeper structures of the brain. Generally, Moniz and his colleague Almeida Lima had good results with the operation, which had a tranquilizing effect on the patients. The operation opened a new line of attack on intractable forms of mental illness, but the advent of psychotropic, or tranquilizing, drugs largely eliminated the need for such action.

In 1927 Moniz made a lasting contribution to diagnosis of intracranial afflictions with his introduction of cerebral angiography—a method of visualizing the blood vessels of the brain by injecting substances opaque to x-rays and following with an x-ray examination. This method was also applied successfully to the study of other organs and to the diagnosis of vascular disease and tumors in other parts of the body.

Moniz was born at Avanca, Portugal,

and received his medical degree from the University of Coimbra in 1899. After teaching there for several years, he specialized in neurology, studying in France, at Bordeaux and Paris. In 1902 he became professor at Coimbra and in 1911 was appointed to the new chair of neurology at Lisbon, holding that position until 1945.

Meanwhile, Moniz took an active part in Portuguese politics. Between 1903 and 1917 he served several times in the Chamber of Deputies. He was named minister to Spain in 1917 and minister of foreign affairs in 1918, leading the Portuguese delegation at the Paris Peace Conference (1918–1919).

MONOD, JACQUES (1910–)

While professor of metabolic chemistry at the Faculté des Sciences in Paris, France, Jacques Monod shared the 1965 Nobel Prize in medicine or physiology with François Jacob and André Lwoff. The three French biologists worked as a team to discover how the activities of cells are regulated. (*See* François Jacob; André Lwoff.)

Monod was born in Paris and in 1932 began his laboratory work on the origins of life. Granted a scholarship by the Rockefeller Foundation, he moved to the United States to complete his training and received a doctorate in 1941. He served as laboratory chief at the Pasteur Institute of Paris from 1945 to 1953 and then became head of its Department of Cellular Biochemistry and also professor at the Faculté des Sciences.

For his bravery during World War II, he was given both the French croix de guerre and the U.S. Bronze Star. He also was made an officer in the French Legion of Honor. In 1962 he won the Leopold Mayer Prize of the French Academy.

MONTGOLFIER, JOSEPH-MICHEL (1740–1810) and JACQUES-ÉTIENNE (1745–1799)

After the late fifteenth century, when Leonardo da Vinci had built his first models of birdlike machines, men persisted in attempts to build mechanical devices that would carry them into the air. It had long been thought that the hydrostatic principle of Archimedes could help man fly, since it had been proved that air has weight, that various gases are lighter than air, and that a vacuum, or absence of air, is much lighter than air. There had even been a project to incorporate evacuated copper spheres as part of a flying machine. The men responsible for man's first flight, however, were two French brothers—one a dreamer, the other the staid manager of a small firm and a shrewd financial speculator. They succeeded with a balloon filled with heated air, without even knowing the nature of the phenomenon that kept them airborne. The ascent took place in 1783, a full 120 years before the Wright brothers' first heavier-than-air flight. The achievement of the two Frenchmen opened a new era—that of atmospheric exploration by means of balloons.

The maiden flight was followed by other successful attempts and, a few years later, by the launching of the first balloons filled with hydrogen—a gas much more efficient than heated air. With these hydrogen-filled balloons, flights were undertaken almost to the limits of the stratosphere long before the invention of the airplane. Extensive meteorological exploration was carried out, and balloon flying was cultivated in Europe and America for scientific, military, and recreational purposes.

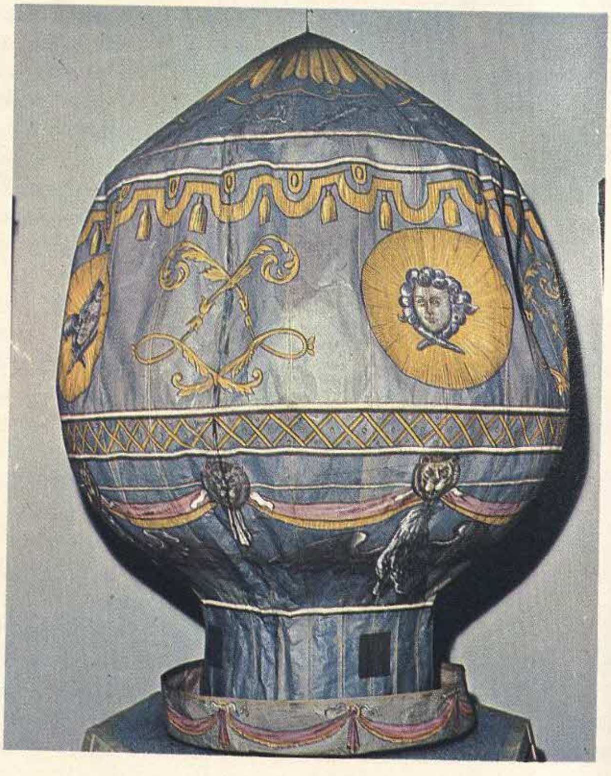
The names of the two brothers, Joseph-Michel and Jacques-Étienne, are inseparable—not only because they were close collaborators but also because their dissimilar characters strangely complemented each other. Joseph, who was impulsive, had a foolhardy and enthusiastic nature, which was offset by the knowledge and reflective capacity of his brother. The two were sons of a paper manufacturer at Vidalon-lez-Annonay, France, who drew enough income from his business to provide generously for his nine children.

Since Joseph was not an outstanding pupil, he went to work in his father's paper factory; but this proved unsatisfactory, and with a brother, Augustin, he opened a firm of his own. He soon went bankrupt, however, and became a traveling salesman. This entailed long journeys on foot, during which he pondered the problems that interested him most. He had already invented a kind of flame-throwing pump, a machine typical of an inventor searching for the most unusual devices imaginable; yet the problem that had most fascinated him since childhood was that of flight. He began to experiment with balloons, and his progress soon aroused the interest of his brother Jacques. The two brothers began to collaborate so closely that at a certain point, it becomes impossible to distinguish between their contributions.

Jacques was the exact opposite of Joseph. He was a good student of architecture but abandoned his studies to join his father's firm. He introduced into France the Dutch mill for the refining of cellulose, and his father's firm consequently became the first in France to produce tissue paper.

Joseph's idea for a heated-air balloon was apparently first inspired by a glimpse of a shirt hung out to dry above a pan of live coals. The shirt swelled and ballooned upward. Joseph decided to make a paper balloon and fill it with steam. If

Montgolfier Brothers


In 1783 man's first flight took place in a balloon designed by Joseph-Michel and Jacques-Étienne Montgolfier, which was similar to this model. Based on the heated-air principle, this was the first practical fire balloon and became known as the montgolfier after its inventors.

the balloon rose, he planned to repeat the experiment on a larger scale. The steam, however, condensed, and the experiment failed. Undismayed, Joseph continued to think about the shirt he had observed. When the shirt had risen, it had assumed the shape of a spherical canopy, and so he decided to make a fresh attempt, this time with spherical canopies heated from below. He gradually extended these canopies until they formed an almost complete sphere.

In the meantime, he tried to send up a balloon filled with hydrogen, but the experiment failed because the gas escaped. Undiscouraged, he performed experiments with paper and taffeta shapes that had something in common with that of the shirt. Although these strange contrivances never actually rose into the air, they fell very slowly when dropped while filled with heated air.

At this stage the brothers collaborated and constructed small balloons that finally became airborne. They showed that the heated-air principle worked and decided to build larger balloons. On June 15, 1783, in the marketplace at Annonay, the Montgolfier brothers carried out their first public flying experiment. It was a modest excursion, without passengers, but they had invited dignitaries for the occasion. Their globe of waxed paper, about 33 feet in diameter, rose to a height of about 1,500 feet, being held up by the heated air produced by a fire of straw and wool burning on a metal grid suspended below the balloon. After being airborne for ten minutes, it landed in a field on the outskirts of Annonay more than 7,500 feet from its starting point.

Their next step was to try the experiment with passengers; and on November 21, 1783, Pilâtre de Rozier, who was a professor of physics at Metz, and the marquis François Laurent d'Arlandes undertook the first flight on board a montgolfier (the fire balloon had by then been named after its inventors). The flight was a dramatic one: a spark flying up from the fire ignited the envelope, but De Rozier promptly extinguished the flames with a wet sponge. The balloon rose from Chateau de la Muette, flew southward over Paris from the northwest, and landed about 5.5 miles from the launching site. It had reached an altitude of more than 3,000 feet and had stayed aloft about twenty-five minutes, displaying above the city its blue and gold emblems and the signs of the zodiac that encircled it. The cloth used for its construction was cotton sealed with albumin.

In June 1785 Pilâtre de Rozier tried to fly across the English Channel, but the balloon caught fire and he was killed. Subsequently, the Montgolfier brothers turned their attention from flying to mechanics and in 1796 invented a hydraulic battering ram. Their greatest invention, however, remained the montgolfier. Louis XVI gave them a monetary prize and rewarded Jacques with the Ribbon of Saint Michael, and Joseph with a pension.

One extraordinary aspect of the Montgolfier brothers' achievement was that they never realized that their balloons took flight because of the expansion and resultant lightness of heated air. They thought that the buoyancy of their balloons was due to the smoke or to some mysterious vapor given off by the fire. At the time, people still believed in the existence of fire as a substance called phlogiston. The Montgolfier brothers could be said, paradoxically, to have flown with phlogiston, a proof that observation, imagination, and intuition have sometimes outstripped the limits of pure scientific research.

MORGAN, THOMAS HUNT (1866–1945)

The U.S. biologist Thomas Hunt Morgan was awarded the 1933 Nobel Prize in physiology or medicine for his work in genetics. The spur to Morgan's valuable discoveries was his skepticism about the reality of genes as actual bodies responsible for the transmission of heredity. He and his colleagues became the first to link specific genes with specific chromosomes.

Morgan was born at Lexington, Kentucky, and took his early training in zoology there, at the State College of Kentucky (now the university). He received his doctorate in 1890 from Johns Hopkins University, Baltimore, Maryland. From 1891 to 1904 he was associate professor of zoology at Bryn Mawr College, Bryn Mawr, Pennsylvania, and from 1904 to 1928 professor of experimental zoology at Columbia University, New York City. In 1928 he left Columbia to establish and direct the Kerckhoff Laboratories of Biological Sciences at the California Institute of Technology, Pasadena, which became a center of genetic research. At Pasadena he returned to his early interest in experimental embryology and, except for vacations in Woods Hole, Massachusetts, remained there for the rest of his life.

During his years at Bryn Mawr, many scientists were becoming interested in heredity. In 1900 three European investigators independently rediscovered and confirmed the laws of heredity that Gregor Mendel had set forth in 1866 with little publicity. At Columbia University in 1909, Morgan began his experimental work with the tiny and prolific insect *Drosophila*, the vinegar fly, commonly known as the fruit fly. Since its cells have only four pairs of chromosomes, the problems of inheritance were reduced to simple terms; and the first chromosome maps for it were being drawn two years later.

Thomas Morgan

By 1915 Morgan and his students, A. H. Sturtevant, H. J. Muller, and C. B. Bridges, had proved the reality of genes as corporeal elements with specific locations in chromosomes of the cell nucleus. The collective principles gleaned from the group's experiments came to be known as the chromosome theory of heredity or the theory of the gene.

Morgan was awarded the Darwin and Copley medals of the Royal Society, which elected him to fellowship in 1919. He was president of the National Academy of Sciences from 1927 to 1931 and of the American Association for the Advancement of Science in 1930, as well as head of the Sixth International Congress of Genetics in 1932. His works include *Development of the Frog's Egg* (1887), *Heredity and Sex* (1913), *Mechanism of Mendelian Heredity* (1915), *The Physical Basis of Heredity* (1919), *Evolution and Genetics* (1925), and *Embryology and Genetics* (1933).

MORLEY, EDWARD WILLIAMS (1838–1923)

The U.S. chemist and physicist Edward Morley conducted research and won fame in important areas of physics and chemistry alike. With Albert A. Michelson he carried out the Michelson-Morley physics experiment on ether drift and the velocity of light. As a chemist he is most noted for determining the weights of hydrogen and oxygen and the ratio in which they combine.

Morley was born in Newark, New Jersey. He began his adult life with the intention of becoming a minister; and after graduating from Williams College in Massachusetts in 1860, he studied at the Andover Theological Seminary to prepare for the Congregational ministry. While waiting for a church position, however, he began studying chemistry and in 1868 was offered a professorship at Western Reserve University, Cleveland, Ohio. Still a devout man, he accepted the professorship on the condition that he could preach in the university chapel. He remained at Western Reserve until he retired as professor emeritus in 1906.

In their famous experiment in 1887 Michelson and Morley attempted to measure the relative velocity of the Earth and the effect this might have on the speed of light. They failed to find any influence of the Earth's motion on the speed of light, and the negative results of their experiment actually formed the basis for Einstein's theory of relativity.

During the 1870s Morley began his work on hydrogen and oxygen and in 1895 succeeded in determining the densities of the two elements. He was also a talented inventor of laboratory apparatus, devising a eudimeter and differential manometers and aiding Michelson with the development of the interferometer used in the Michelson-Morley experiment.

MORSE, SAMUEL FINLEY BREESE
(1791–1872)

Scattered in various private collections and museums are more than 300 paintings by the U.S. artist-scientist Samuel Morse, whose name, however, is linked primarily with the invention of the electric telegraph and of the codified alphabet transmitted by the apparatus. Today there are machines that can do extremely complicated calculations and think out these calculations in a language similar to the one that Morse invented for the long-distance transmission of his messages with an electric apparatus. Although it is now relatively simple to invent these machine languages, more than 150 years ago the invention of the first such machine was an exceptional undertaking. Moreover, there was the difficulty of proving the usefulness of an apparatus that could transmit man's thoughts over long distances.

Morse was born in Charlestown, Massachusetts, to a family with long-established Puritan traditions. His father, Jedidiah, was an impulsive and eccentric man, who combined his pastoral duties with a passion for geography; and his mother, Elizabeth Ann Breese, was a woman gifted with wisdom and intelligence. Of their eleven children, only three survived, one of whom was Samuel. At age fourteen, after studying in his native town and then at Phillips Academy, Andover, he went to Yale University, where he started to take a definite interest in the two subjects that were to dominate his life: painting and electricity. The second attracted him greatly but only as an object of study; perhaps he did not wish to embark on a career that at that time offered no great possibilities of practical application. On the other hand, where art was concerned, he felt confident: he knew how to handle brush and pencil and so decided to take up an artistic career.

In 1811 he accompanied his friend and teacher Washington Allston to England, where he studied with Benjamin West, a famous American painter who lived in London and who gave a warm welcome to his young compatriot. Morse must have benefited from his teaching because on October 13 of that year he was awarded the gold medal of the Arts Society for his work *The Dying Hercules*. After his final studies in 1815, he felt ready to begin working independently and therefore returned to his own country to start his career. He traveled from city to city looking for people who wanted their portraits painted, usually for a modest sum. Apparently while his brush was moving over the canvas, his mind was free to think, because during this same period he invented a pressure pump that could be used for fire-fighting purposes.

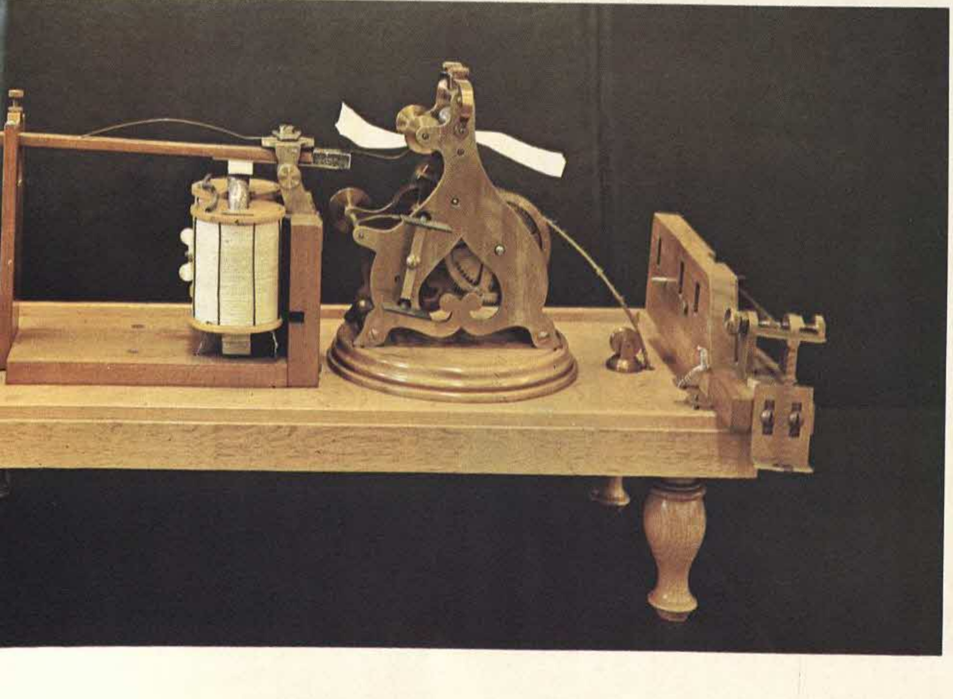
His travels finally took him to Boston, where he fell in love with Lucy Walker, whom he married within a few weeks. They settled at first in Charlestown and then in New Haven, Connecticut. The following years were the bitterest of his life because, although he worked indefatigably, he was unable to provide adequately for his wife and three children and frequently had to spend long periods away from them.

Finally success came when he was commissioned to paint the portrait of his first famous client, the marquis Lafayette; but it actually came too late: before he could return home, his beloved wife died of a heart disease. His success grew daily, and he was much in demand as a portrait painter. He gave lectures; founded the National Academy of Design, becoming its first president; and, with John William Draper, introduced the Daguerre process to the United States.

In 1829 he returned to Europe; and after visiting the most famous museums, where he drew inspiration from the masters, he settled in Paris and became one of the most active members of the American artists' colony there. One day when he was in the company of friends, the conversation turned to the subject of communications. Somebody stressed the need for some rapid means of sending messages, and Morse immediately suggested: "Why not electricity? It travels faster than sound."

At that time the horse provided practically the fastest means of communication. It therefore took weeks if not months for news to reach Moscow from Paris. Clearly, the need for swifter means of communication was strongly felt in a

By means of a code of dots and dashes—which now bears his name—sent over a simple electrical apparatus, Samuel Morse, on January 24, 1838, at New York University, transmitted the first telegraphic message: "Calling the Universe!"



Samuel Morse

rapidly evolving world on the eve of the Industrial Revolution, when consumption, production, and trade were steadily increasing.

The remark, thrown out during a casual conversation with friends, obsessed the painter as he crossed the Atlantic aboard the *Sully* bound for home. Soon even the captain of the ship and the passengers were discussing Morse's ideas as they gradually took shape. The long-distance transmission of messages had become a fixation with him, and his sketchbook no longer contained portraits and drawings of figures and landscapes but the rudimentary plans of the telegraph. At home he continued his search for improvements, though knowing full well that the development of his idea in a commercially viable form would involve a great deal of effort; in fact, he worked a full twelve years on its realization. At first he continued to travel and paint portraits in order to raise money, which he needed not only to live but also to carry out his experiments. Then he retired to New York City, where he lived in a single room, researching and experimenting, with hardly a thought for his food and clothes. To avoid borrowing money, he sold all his possessions and lived on a bare minimum. The once elegant and popular artist had turned into a down-at-heel inventor who was thought mad because he had abandoned a brilliant career for an impossible dream.

Finally, on September 2, 1837, he was able to show a group of friends his invention: a 1,377-foot-long telegraph circuit. Among those present at this memorable demonstration was Alfred Vail, a wealthy foundry owner with great business acumen. He offered to finance the commercial launching of Morse's invention, for which he predicted a brilliant future, and gave Morse money and working space in his foundry so that the inventor could carry on with his experiments. Morse accepted and immediately filed the patent for his invention.

On January 24, 1838, he gave a demonstration of his apparatus at New York University, transmitting the first message: "Calling the Universe!" In February he repeated it before the U.S. Congress, but it was unenthusiastically received. Since the United States seemed unwilling to take an interest in the telegraph, he left for Europe; but in England two inventors had already invented something similar, in France he was able to file the patent but without any offer of payment, and in Russia the czar showed a complete lack of interest.

In the meantime, Morse was not wasting his time. He knew that having realized the original plan, it was necessary to build an apparatus that could transmit over greater distances; and he started to work on the ideas that would make the application of his principle a practical possibility. His first idea was that of using electric signals; his second, that of the code that he invented, which now bears his name; and his third, that of a relay system to transmit the signal over long distances. Because an electric signal grows weak if transmitted over a long line, Morse decided to use it, before it became too attenuated, to actuate a key that would send off a new, strengthened signal on a fresh stretch of line. On his return to the United States, however, he was reduced almost to pauperdom, and it was not until 1843 that he was granted a first appropriation of funds by Congress. On May 24, 1844, the first experimental line was inaugurated between Washington, D.C., and Baltimore, Maryland, over a distance of thirty-five miles. One of Morse's friends chose the sentence to be transmitted for the inauguration: "What hath God wrought!"

Contracts were nonetheless slow in materializing; moreover, he had to face a series of accusations and lawsuits to defend his own rights. The evidence of the captain of the *Sully* and of the ship's passengers on that crossing from Europe to the United States many years before finally convinced the courts, however; and at this rather late stage of his life, he was at last able to savor the joys of success. He became rich and famous, married a second wife, Sarah Griswold, received honors from all over the world, traveled, and saw the triumph of his inventions wherever he went—from the transatlantic cable telegraph to the universal use of his code alphabet.

MORTON, WILLIAM THOMAS GREEN

(1819–1868)

The nineteenth-century U.S. dental surgeon William Morton conducted the first public demonstration of the use of ether as an anesthetic in surgery. Although he was not the first to perform an operation with a patient under ether, he was the one who made its value known to the medical world.

Morton was a native of Charlton, Massachusetts. In 1844, after studying dentistry at Baltimore College of Dental Surgery in Maryland, he went into dental practice in Boston, Massachusetts, concentrating on the improvement of artificial teeth and their means of attachment. In searching for a way to deaden the pain of extraction, he became interested in anesthesia through another dentist, Horace Wells, who had used nitrous oxide gas. Charles T. Jackson, a Boston chemist who had already made laboratory experiments involving inhalation of ether, suggested its use to Morton and demonstrated the method for him. In September 1846, Morton successfully used ether in the extraction of a tooth and the following month publicly administered ether at Massachusetts General Hospital while a physician removed a tumor from a patient's neck. The success of that demonstration established anesthesia as an essential part of a surgical operation.

Morton patented the process in collaboration with Jackson in lieu of the large fee that Jackson demanded for his advice and Morton could not afford. Jackson, however, began a lifelong fight to claim the credit for discovering ether anesthesia, and similar claims were made by others. Because of this ruinous litigation, Morton died in poverty.

A bill introduced into the U.S. Congress to vote $100,000 for Morton as a testimonial of national gratitude failed to pass in 1852, 1853, and 1854. In 1920, however, Morton was elected to the Hall of Fame for Great Americans.

Anesthesia was established as an essential part of a surgical operation when—on October 16, 1846, at Massachusetts General Hospital in Boston—William Morton administered ether to a patient who was having a tumor removed.

MOSELEY, HENRY GWYN-JEFFREYS
(1887–1915)

A battle during World War I claimed the life of one of the most promising young scientists of the early twentieth century, the English physicist Henry Moseley. Before his early death he had already done significant research on the x-ray characteristics of elements, and his work had led to important improvements in the periodic table.

Henry Moseley

Moseley was born at Weymouth, Dorsetshire, England, the son of a naturalist and professor of anatomy, and grandson of a noted mathematician. He received his education at Eton and at Trinity College, Oxford, and in 1910 went to the University of Manchester, where he first lectured in physics and later became a research fellow in the laboratory of Sir Ernest Rutherford.

His first research work was on radioactivity, but soon he became interested in the x-ray spectra of the elements. Following up on the work of W. H. and W. L. Bragg and Max Laue in the area of x-ray crystallography, he decided to use the x-ray technique for investigating the x-ray radiations characteristic of each element. He demonstrated experimentally that the frequencies of the characteristic x-ray emissions in a series of elements changed regularly from one element to the next. The wavelengths decreased as the atomic weight of each element from which they were emitted increased. Since the regularity of the changes could not have been due to the changes in atomic weight, Moseley attributed it to the nuclear charge.

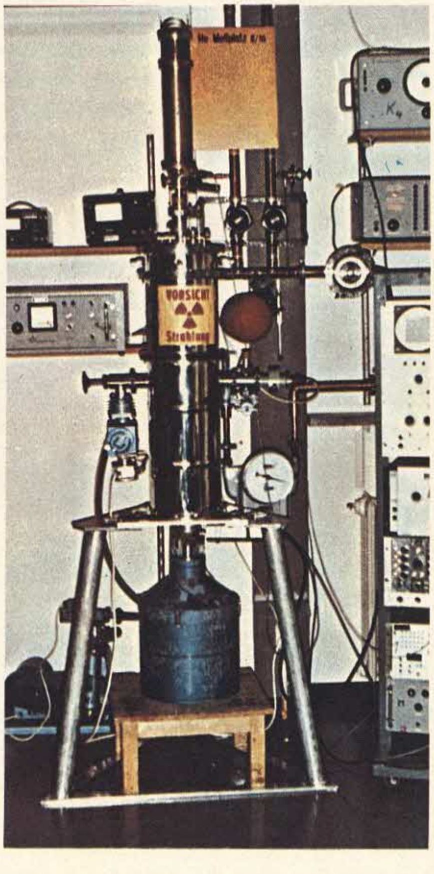
On the basis of this experimental work, Moseley introduced the concept of atomic number. He modified the periodic table, arranging the elements according to their atomic number rather than their atomic weight. Arranged in this way, there was no doubt about the order in which the elements followed one another. Furthermore, working with his x-ray technique, Moseley found it possible to determine whether or not there were any undiscovered elements and exactly what position they should occupy in the periodic table. In 1914, at the time that he published his findings, there were seven missing elements between atomic numbers 1 (hydrogen) and 92 (uranium).

After doing research at Oxford in 1913 and making a trip to Australia in 1914, Moseley enlisted as a lieutenant in the Royal Engineers. In June 1915 he was sent to Gallipoli and shortly thereafter was killed in action.

MÖSSBAUER, RUDOLF LUDWIG
(1929–   )

The German physicist Rudolf Ludwig Mössbauer received the 1961 Nobel Prize in physics for his discovery and 1958 report of the Mössbauer effect. The award, which he shared with Robert Hofstadter, recognized his research in recoilless gamma-ray resonance absorption, in which he provided a way to compare, with unprecedented precision, the resonant frequencies, or excitation energies, of atomic nuclei. (*See* Robert Hofstadter.)

In his studies of what is now known as the Mössbauer effect, or recoilless gamma-ray resonance absorption, Rudolf Mössbauer used apparatus of his own design.



Rudolf Mössbauer

The Mössbauer effect was applied in testing Einstein's theory that light or other electromagnetic radiation is distorted by gravity. It was also used chemically to test the nuclear characteristics and valence properties of atoms.

Mössbauer, the only son of a phototechnician, was born in Munich and majored in physics at the Technische Hochschule there, receiving his bachelor's degree in 1953 and his master's in 1955. After earning his doctorate in 1958 with a thesis written while a research assistant at the Max Planck Institute of Heidelberg University, he remained at the Technische Hochschule as a research fellow until 1960, when he was appointed senior research fellow at the California Institute of Technology, Pasadena. He later became professor of physics there but in 1964 returned to Munich as professor of physics at the Technische Hochschule. In 1961, in addition to the Nobel Prize, he was granted the Research Corporation Award, the Röntgenpreis from the University of Giessen, and the Cresson Medal of the Franklin Institute.

MULLER, HERMANN JOSEPH (1890–1967)

The U.S. geneticist Hermann Muller discovered the production of artificial mutations of genes by x-rays. For this achievement he was awarded the 1946 Nobel Prize in physiology or medicine. As a result of his studies in radiation, Muller was one of the first men to warn of the dangers in excessive use of medical x-rays and to outline the hazards of atomic fallout.

Muller was born in New York City and studied at Columbia University, where he was a member of a group that worked on the genetics of the fruit fly. After receiving a doctorate in 1916, he accepted a position as instructor of biology at Rice Institute, Houston, Texas; in 1918 he returned to Columbia; and in 1920 he went to the University of Texas, where he remained for twelve years. In 1932 he went to Berlin, Germany, on a Guggenheim Foundation Fellowship, and in 1933 he was invited to join the Institute of Genetics of the U.S.S.R. Academy of Sciences as a senior geneticist. Disappointed with Marxism, he left the academy in 1937 and joined the Institute of Animal Genetics of Edinburgh University in Scotland.

Hermann Müller

On his return to the United States in 1940, he spent five years at Amherst College in Massachusetts before joining the faculty of Indiana University, where he became Distinguished Service Professor in 1953 and professor emeritus in 1964. He was a member of the City of Hope Medical Center in Duarte, California, in 1965 and visiting professor at the University of Wisconsin the following year.

Müller was elected to the National Academy of Sciences in 1931. His publications include *Out of the Night, a Biologist's View of the Future* (1935) and *Studies in Genetics* (1963).

MÜLLER, JOHANN (1436–1476)

One of the most advanced astronomers and mathematicians of his time was Johann Müller, the son of a German miller. He prepared tables of planetary motion and other data that were useful to navigators of the fifteenth century, when the long voyages of exploration began.

Born in Königsberg, Franconia, a duchy of medieval Germany, Müller came to call himself Johann de Monteregio after the name of his birthplace, meaning "king's mountain." Later he was known as Regiomontanus, the Latin form. In 1452 he went to Vienna, Austria, where he studied with Georg Purbach and assisted him in the preparation of a work on Ptolemaic astronomy. Purbach's work was completed in 1463 and published in Venice in 1496. Müller spent the years between 1462 and 1468 in Rome and other cities of Italy, where he met with leading astronomers and worked on his important *De triangulis,* which provided a systematic basis for the development of trigonometry. He returned to Vienna in 1468 and from there went to Buda to collate Greek manuscripts at the invitation of the king of Hungary. In 1471 he settled in Nürnberg, where he was befriended by Bernard Walther, a wealthy amateur astronomer who became his student and patron, providing him with an observatory and a workshop, in which Müller made improved instruments that are described in his *Scripta,* published posthumously in 1544.

Although Müller had considerable mechanical ability, he was chiefly a compiler and disseminator of mathematical knowledge and introduced to Germany the use of Arabic methods in algebra and trigonometry. In 1472 he observed a great comet and in the same year established a printing press in Walther's house. Among the works that issued from the press were a series of calendars and learned works, including one describing a method for determining longitude at sea. Müller's fame spread to the extent that he was called to Rome in 1475 to be an adviser on the reform of the Julian calendar, but he died of the plague the following year.

MÜLLER, JOHANNES PETER (1801–1858)

The German physiologist and anatomist Johannes Peter Müller made many contributions to medical and biological science through his work in the fields of descriptive anatomy, embryology, histology, and comparative anatomy. He was one of the first scientists to apply microscopy to pathological studies, and his outstanding textbook on physiology presented the new experimental approach to the subject. He is sometimes referred to as the founder of modern physiology.

One of Müller's greatest accomplishments was the discovery in 1826 of specific nerve energies. He found that the form of stimulation has nothing to do with the sensation recorded and that a certain type of nerve will record only one sensation; for example, the optic nerve will register only the sensation of light no matter what type of stimulation it receives. He also discovered the pronephric (Müller) ducts in embryos, and lymph hearts in frogs; did research on the chemistry of the blood and on reflex actions; and studied the mechanism of the vocal chords and investigated tone production in the voice.

Müller was born at Coblenz and studied medicine at the University of Bonn, graduating in 1822. Two years later he joined the faculty at Bonn as a lecturer and became an associate professor in 1826 and a full professor in 1830. He was appointed professor of anatomy and physiology at the University of Berlin in 1833, and in 1840 was elected a foreign member of the Royal Society.

Müller was a neurotic man and suffered several nervous breakdowns. The strain of handling student disorders during the Revolution of 1848 had an adverse effect upon his health, and there is even some evidence that he may have committed suicide.

MÜLLER, PAUL HERMANN (1899–1965)

The Swiss chemist Paul Müller discovered the insecticidal properties of dichlorodiphenyltrichloroethane, commonly abbreviated as DDT. For this accomplishment he was awarded the 1948 Nobel Prize in physiology or medicine.

DDT was first tested in 1939 and found to be effective. During World War II it was valuable in combating epidemics of typhus fever, and after the war it was used for agricultural purposes. Although its usefulness was eventually limited by the growing resistance of the insects, its benefits to mankind were of lasting importance.

Müller was born in Olten, Switzerland, and attended the University of Basel for a time. He left to become a laboratory assistant at a private chemical firm but returned to school in 1918 and began graduate study in chemistry the following year. After receiving his doctorate in 1925, he joined the research department of the J. R. Geigy Company in Basel. By 1930 he had developed two synthetic tanning substances, and in 1935 he began working on the development of an insecticide for the control of agricultural pests. Four years later, after experimenting with hundreds of different substances, he discovered DDT, which proved to be an ideal weapon against insects.

MULLIKEN, ROBERT SANDERSON (1896–)

The winner of the 1966 Nobel Prize in chemistry was the U.S. scientist Robert S. Mulliken, who had applied principles of quantum mechanics to problems associated with the atom. "Mr. Molecule," as he was called, was awarded the prize for "fundamental work concerning chemical bonds and the electronic structure of molecules by molecular orbital method."

Mulliken was born in Newburyport, Massachusetts, the son of a professor of organic chemistry. He graduated from the Massachusetts Institute of Technology in 1917 and received his doctorate from the University of Chicago in 1921. From 1921 to 1925 he was a National Research Council fellow both at Chicago and Harvard; and after teaching two years at New York University he served as associate professor and professor at the University of Chicago, 1926–1961, the last five years as the Ernest DeWitt Burton Distinguished Service Professor. During World War II he played a key role in atomic bomb research, and after the war he served for a time as science attaché to the U.S. embassy in London, England. On becoming professor emeritus after 1961, he divided his time as Distinguished Service Professor of Physics and Chemistry at Chicago and as Distinguished Service Professor of Chemical Physics at Florida State University during the winter months.

Robert Mulliken

Mulliken was honored with many awards. In 1936 he was elected to the National Academy of Sciences; and in 1960 he received the Gilbert Newton Lewis and the Theodore William Richards medals of the American Chemical Society, in 1963 the Peter Debye Award, in 1964 the John G. Kirkwood Medal, and in 1965 the Willard Gibbs Medal.

MURPHY, WILLIAM PARRY (1892–)

The U.S. physician Willam Parry Murphy won the 1934 Nobel Prize in medicine or physiology with G. R. Minot for the successful control of pernicious anemia by means of a liver diet. Their co-winner was G. H. Whipple, who discovered that liver stimulates blood production. (*See* George Richards Minot; George Hoyt Whipple.)

Murphy was born in Stoughton, Wisconsin, and received his bachelor's degree from the University of Oregon in 1914. After teaching physics and mathematics in Oregon high schools for two years, he entered the medical school of Harvard University, Cambridge, Massachusetts. On graduating in 1920, he served as house officer at Rhode Island Hospital in Providence, Rhode Island, until 1922, and the following year began to practice medicine in Boston, Massachusetts. Subsequently, he received successive appointments as assistant resident, junior associate, associate, and senior associate in medicine and consultant in hematology at the Peter Bent Brigham Hospital there. Begining in 1923, he was successively assistant in medicine, instructor, associate, and lecturer at the Harvard University Medical School.

William Murphy

Murphy and Minot began to feed patients up to a half pound of liver daily in 1924 after Whipple's findings led Minot to suspect that certain foods might achieve favorable results in pernicious anemia, a fatal disease in which the red blood corpuscle count declines progressively; and in 1926 they announced highly favorable results. Their discovery and the developments that followed changed pernicious anemia into an eminently treatable ailment. Murphy's book *Anemia in Practice* was published in 1939.

NANSEN, FRIDTJOF (1861–1930)

High adventure and great accomplishment characterized the life of Fridtjof Nansen—Norwegian explorer, scientist, artist, statesman, and humanitarian. His scientific work was his chief line of endeavor, though he first gained fame as an explorer. In his later years he was active in international relief work, for which he received the 1922 Nobel Peace Prize.

Nansen was born at Store-Fröen near Christiania (now Oslo), Norway, and studied at the university in Christiania. An athlete and an avid hunter and fisherman, he chose to study zoology, which would permit him time outdoors.

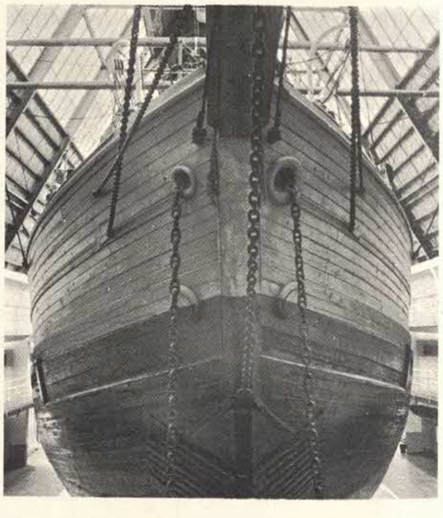
His first encounter with Arctic conditions was on a sealing expedition in 1882 when a glimpse of Greenland's ice cap fired his ambition to cross it. On August 16, 1887, Nansen's expedition of six started the crossing—not from the inhabited west coast but from the east coast so that they would not have the means of retreating and would have to press forward. Through storms and cold, the party reached the highest point of the journey—8,920 feet—on September 5 and arrived at the west coast at Ameralik Fjord on September 26. Wintering at Godthaab gave Nansen the opportunity to study Eskimos, an experience that resulted in his *Eskimoliv* (1891; English translation, *Eskimo Life*, 1893). The party returned to Norway in May 1889.

Soon Nansen set about raising funds for another hazardous expedition. Recognizing that the ice of the Polar Sea drifts from Siberia toward the Arctic island of Spitsbergen, Nansen proposed to build a ship that would be lifted—not crushed—when caught in the ice. He planned to let the ship freeze in off eastern Siberia and then be carried by the currents. With grants from the Norwegian parliament, king, and private citizens, Nansen built the *Fram* ("Forward"), which today is preserved outside Oslo. On June 24, 1893, the *Fram* sailed from Christiania with thirteen men aboard and by September 22 was enclosed by the ice, bearing the pressure perfectly. Then began the long drift, which ended triumphantly north of Spitsbergen almost three years later when the *Fram* was released from the ice.

In March 1895 Nansen left the *Fram* and, accompanied by F. H. Johansen, started northward with dogsleds and kayaks to explore the uninhabited land. They were the first ever to reach the latitude of 86° 13.6′ N. Heading for Franz Josef Land, they were hampered by open water and severe weather and so built a stone hut and settled for the winter, living mainly on the meat of polar bear and walrus. On the way to Spitsbergen in the following spring, they had the good fortune to meet the British Arctic explorer Frederick Jackson and his party and returned to Norway on his ship, arriving eight days before the *Fram* and its tremendous collection of scientific data. Nansen's two-volume account of the expedition, *Fram over Polhavet* (*Farthest North*), was published in 1897.

In 1882 Nansen had been appointed curator of zoology at the Bergen Museum.

The ship *Fram*, which Fridtjof Nansen used on some of his Arctic explorations, is today preserved in a museum in Oslo, Norway.



Fridtjof Nansen

and he wrote and illustrated many papers on zoological and histological subjects. For his paper "The Structure and Combination of Histological Elements of the Central Nervous System" (1887), he was awarded a doctorate degree by Christiania University; and on his return from the Fram expedition he was appointed professor in zoology. His interests shifted to physical oceanography, however, and in 1908 his status was changed to professor of oceanography. From 1896 to 1917 Nansen devoted most of his time to scientific work. He took part in the establishment of the International Council for the Exploration of the Sea and made several scientific cruises, studying conditions in the Norwegian Sea and the northeastern Atlantic Ocean. His contributions to oceanography included the improved design of instruments and the explanation of wind-driven currents.

Nansen was active in the separation of Norway from Sweden in 1905 and served as Norway's first minister to England from 1906 to 1908. In 1917, during World War I, he headed a Norwegian commission to the United States for negotiating an agreement on the importing of essential supplies. At the first assembly of the League of Nations in 1920, Nansen headed the Norwegian delegation and was given the task of repatriating from Russia 500,000 prisoners of war who had served in the German and Austro-Hungarian armies. Nansen completed the assignment successfully and went on to perform other outstanding international relief work, even using his Nobel Prize money to that end.

NAPIER, JOHN (1550–1617)

The eighth laird of Merchiston and prominent Scottish mathematician John Napier was the inventor of logarithms. He was born at Merchiston Castle near Edinburgh, Scotland, and entered the University of Saint Andrews at age thirteen. He left without obtaining a degree, however, and apparently traveled abroad for several years before settling permanently in Scotland in 1571. A devout and outspoken Protestant, Napier was involved in a number of bitter quarrels with the Church of Rome. His great work *A Plain Discovery of the Whole Revelation of Saint John* is important in Scottish ecclesiastical history, being the first such Scottish interpretation of the Scriptures.

After the appearance of this publication, Napier devoted himself to inventing secret war weapons, including artillery and a chariot from which pellets could be shot through small holes. He also was interested in mathematics, especially methods of making computations less difficult, and devised logarithms, his most important contribution. These are explained in two treatises, one published in 1614 and another published posthumously in 1619. Napier was also the author of several books on multiplication, division, and spherical trigonometry.

NATTA, GIULIO (1903–)

For his fundamental research on the structure of olefin polymers the Italian chemist Giulio Natta shared in the 1963 Nobel Prize in chemistry. The co-winner was the German chemist Karl Ziegler. (*See* Karl Ziegler.)

Natta, the son of a judge, was born at Imperia, near Genoa, Italy. After receiving his doctorate in chemical engineering from the Polytechnic Institute of Milan in 1924, he held successively the chair of general chemistry at the University of Pavia, physical chemistry at the University of Rome, and industrial chemistry at the Polytechnic Institute of Turin. In 1938 he returned to the Polytechnic Institute in Milan as professor of industrial chemistry and director of its Industrial Chemistry Research Institute.

Natta began his scientific research in 1923, applying x-rays to the study of the lattice structure of organic and inorganic chemical substances. In 1932, to learn new techniques in the study of interferences of electron rays, he went to Freiburg, Germany, where he became acquainted with macromolecular chemistry and started his research on the crystal structure of high polymers. (Polymers are large chainlike molecules formed by combining many small molecules; high polymers have high molecular weight.) His related studies on catalysis enabled him to do original research on the synthesis of methanol.

With his colleagues, the Italian chemist Giulio Natta performed experiments vital to industrial chemistry.

In 1938, when the Italian government appointed him to organize research for the production of synthetic rubber, Natta began to study petrochemical problems. His background facilitated his work on the production of high polymers from petroleum and enabled him to develop the processes for obtaining new classes of macromolecules from cheap raw materials produced by the petroleum industry.

Natta is known best for his discoveries made after 1953, when he started his intensive studies on macromolecular chemistry. Learning about Ziegler's development of organometallic catalysts for polymer formation, Natta applied the Ziegler catalysts to the polymerization of propylene. He found that part of the polymer was highly crystalline, saw that it must have been built up with a high degree of uniform three-dimensional order, and proved the structure by using x-ray methods. The word *isotactic* was coined to describe this stereochemical regularity of structure in the repeating units of a polymer. Natta went on to discover variants of the Ziegler catalyst system, thus making possible the high-yield isotactical polymerization of propylene and other olefins. The isotactic polymers became commercially important as plastics, films, and synthetic fibers because of their strength and high melting point.

NÉEL, LOUIS EUGÈNE FÉLIX (1904–)

The French physicist Louis Eugène Félix Néel, whose basic research in magnetism had important applications in the field of electronics, shared the 1970 Nobel Prize in physics with Hannes O. G. Alfvén of Sweden. Néel's work was described as fundamental to a deeper understanding of the way in which magnetic molecules behave. (*See* Hannes Olaf Gösta Alfén, *Addendum, Volume 20.*)

A new category of magnetic substances made its appearance in the 1930s as a result of Néel's investigation of magnetic creep—variations in the magnetization of ferromagnetic substances caused by heat or changes in the distribution of atoms.

Neel later demonstrated that the strength and shape of the zones of magnetism in these materials can be predicted. His research had a great impact on computers, telephones, and microphones.

Néel was born in Lyons, France, and studied in Paris at the École Normale Supérieure, where he earned his doctorate in 1932. For many years he was professor at the University of Strasbourg, but in 1947 he became professor at the University of Grenoble and later was made director of its higher national school of electrotechnics, hydraulics, radio electricity, and applied mathematics. He also served as director of the Polytechnic Institute and of the Center for Nuclear Studies of Grenoble and represented France on the Scientific Council of the North Atlantic Treaty Organization.

Early in World War II, Néel developed a procedure for protecting French combat ships against magnetic mines. The invention consisted of giving the ship a permanent magnetization in a direction that was opposite to the terrestrial magnetic field.

Néel published more than 200 papers and received many awards and honorary degrees. He was made a Grand Officer of his country's Legion of Honor, as well as a member of the Academy of Sciences of Paris and a foreign member of the Royal Society of London, the American Academy of Arts and Sciences, and of Dutch, German, Rumanian, and Russian academies. His awards included the Gold Medal of the National Center for Scientific Research and the Holweck Medal of the Institute of Physics, London, England.

NERNST, WALTHER HERMANN
(1864–1941)

The greatest accomplishment of the German chemist and physicist Walther Nernst was his discovery of the third law of thermodynamics, or the heat theorem, which states that the principle of maximum work holds true only at temperatures near absolute zero. For this work he was awarded the 1920 Nobel Prize in chemistry.

In addition, he did important work in electrochemistry, photochemistry, and solid-state chemistry and is regarded as one of the founders of modern physical chemistry. He also studied chemical equilibria and investigated the specific heat of solids at low temperatures. Among his inventions were a type of incandescent lamp and an electric piano. Some of his earliest work was on the generation of electric current in the galvanic cell, and he developed theories of galvanism important to modern electrochemistry.

In his investigations of the theory of ions, he devised ways of measuring dielectric constants and pH, which is a measure of the concentration of hydrogen ions in a solution. He explained that within a water solution the positively and negatively charged ions are kept apart, which enables the ions to conduct an electric current.

Working in photochemistry, he explained the violent reaction between hydrogen and chlorine when the two elements are exposed to light. He found that initially the chlorine molecule is broken down into two chlorine atoms by the effect of the light and that each such chlorine atom, much more active than the chlorine molecule, reacts with the hydrogen molecule.

Walther Nernst

Nernst was born in Briesen, West Prussia, and studied chemistry and physics at the universities of Berlin; Graz, Austria, and Zürich, Switzerland. After obtaining his doctorate from the University of Würzburg in 1887, he became an assistant to Friedrich Wilhelm Ostwald at the University of Leipzig, Germany. He joined the physics faculty at the University of Göttingen in 1890 and became professor of chemistry there the following year and professor of physical chemistry in 1894. In 1905 he went to the University of Berlin as professor of chemistry and in 1924 became director of its Institute for Experimental Physics, a position he held until his retirement in 1933.

NEUMANN, JOHN VON (1903–1957)

One of the outstanding mathematicians of the twentieth century was Hungarian-American John von Neumann. He founded the theory of operator rings, contributed greatly to the development of high-speed digital computers, and helped in the design of both the atomic and hydrogen bombs.

Von Neumann was born in Budapest, Hungary. He was a child prodigy and at age twenty received his doctorate in mathematics from the University of Budapest and a degree in chemical engineering from the Federal Institute of Technology in Zürich, Switzerland. In 1926 he became a lecturer at the University of Berlin and in 1929 was named assistant professor at the University of Hamburg. The following year he went to Princeton University, where he became a professor of mathematical physics and in 1933, on its founding, professor of mathematics at the Institute for Advanced Study, a post he held for the rest of his life.

His activities were not confined to teaching. During World War II he worked with U.S. Army and Navy scientists, and his concept of implosion helped speed the construction of the atomic bomb at Los Alamos, New Mexico. He was director of a federal electronic computer program from 1945 to 1955, and his efforts in this capacity helped in developing the hydrogen bomb.

In 1954 he was named to the U.S. Atomic Energy Commission and in 1956 was awarded its Enrico Fermi Award. His published works include *Mathematical Foundations of Quantum Mechanics* (1926; English translation, 1955), *Theory of Games and Economic Behavior* (with Morgenstern, 1944), *Collected Works* (volumes 1–3, 1961–1962; volumes 4–6, 1963), and *Theory of Self-Reproducing Automata* (published posthumously, 1966).

NEWCOMB, SIMON (1835–1909)

Although he received little formal education as a child in Wallace, Nova Scotia, his birthplace, Simon Newcomb displayed an interest in, and facility for, mathematics at an early age. Later in life, however, his particular genius was focused on the study of astronomy, with emphasis on the movements of the moon and the planets.

A paper written in 1860 attacking the hypothesis that the bodies of the planetoid zone resulted from the disintegration of a planet formerly orbiting between Mars and Jupiter brought Newcomb to the attention of contemporary astronomers. This was the first of his more than 350 papers on the origin of celestial bodies and their motions. Because his works appealed to the general public, as well as to the scientific community, Newcomb is credited with making the complexities of astronomy comprehensible to a wide audience of readers.

One of Newcomb's most valuable contributions was a history of the moon's motion from the late seventeenth to the late nineteenth centuries. With the publication of an extensive series of tables of lunar and planetary positions in the *Astronomical Papers of the American Ephemeris* in 1899, he completed the monumental task begun twenty-five years earlier.

Newcomb moved to the United States in 1853 and graduated from Harvard University five years later. He began his academic career in 1861 as professor of mathematics at the Washington Naval Observatory, where he determined the position of numerous celestial objects with meridian instruments and refractors. During his long association with the U.S. Navy Newcomb rose to the rank of rear admiral and in 1877 was put in charge of the American Nautical Almanac office, a position he held until 1897. Meanwhile, from 1884 to 1893, he also taught mathematics and astronomy at Johns Hopkins University, Baltimore, Maryland, and edited the *American Journal of Mathematics.*

Newcomb was one of the founders of the American Astronomical Society and served as its first president. As an internationally prominent scholar and educator, he received honorary degrees from ten European and seven U.S. universities, as well as recognition by the Royal Astronomical Society and the National Academy of Sciences. Twenty-four years after his death in Washington, D.C., he was elected to a position in the Hall of Fame for Great Americans.

NEWTON, SIR ISAAC (1642–1727)

Much of science as it is known today and many of the methods used for solving the problems of nature have their origin in the studies of the English mathematician, physical scientist, and natural philosopher Sir Isaac Newton. At the beginning of the seventeenth century, Galileo's experimental method and discoveries had led to a broadening of the horizons of knowledge but to no fundamental conquest. Scientists collected data but had no means of interpreting them. The fact that a scientist like Johannes Kepler had found laws to describe the movement of the planets was undeniably a great achievement; but these laws, which had been deduced from the observation of the planets and their movements, could not be deduced from the laws of mechanics studied by Galileo, because in those times no mathematical means were known for carrying out such a deduction.

Mathematicians had almost clarified the notion of mathematical limit but had stopped on the brink of the invention of a new form of mathematical calculation: that of variable quantities. This invention, together with the discovery of the law of gravitation, led to a greater scientific advance during Newton's lifetime than in all the preceding centuries. Newton's extraordinary discoveries were the product of a mind gifted with an almost superhuman capacity for reasoning and concentration. The greatest mathematicians of Europe spent years thinking out complicated problems to try to baffle him, but Newton always solved them easily, sometimes after a day's participation in other activities.

Newton, the only exceptional member of his family, was born in Woolsthorpe, Lincolnshire, England, on Christmas Day in the year of Galileo's death. He was the posthumous son of a modest tenant farmer. Throughout his childhood Newton was weak and sickly; and his mother, who had remarried soon after he was born, entrusted him to the care of his maternal grandmother. He was sent first to the village school and then continued his studies at nearby Grantham College. While there he lived with the village chemist, whose house held a dual interest for him: a collection of old books, some of them scientific, and the chemist's niece, with whom he fell in love. He became engaged to her; but when he entered Cambridge University, he neglected her so completely that she married someone else. There seems to have been no other romantic interest in his life.

Sir Isaac Newton

At Cambridge, Newton was fortunate enough to have as a professor the English mathematician and theologian Isaac Barrow (1630–1677). The latter took a special interest in Newton, who was slightly older than his companions, taciturn, conscientious, and brilliant. When Barrow decided to devote himself entirely to theology and therefore resigned his chair in mathematics, he recommended Newton; and thus, at the age of only twenty-six, Newton was appointed to a professorial chair at Trinity College.

The subject of optics was of chief interest to Newton at this time. Using a glass prism, he performed the unforgettable experiment of breaking down a ray of light and thereby revealed that white light is a mixture of all colors and that a prism separates the mixture into its component parts because the light of each color is refracted at a different angle.

Led by his prism experiments to the erroneous conclusion that it would be impossible to make a lens system free of chromatic aberration, Newton devised a new type of telescope, called the reflecting telescope because its main light-gathering component was a mirror rather than the lens system of the refracting telescope. With this instrument, which was destined to become extremely important, he gained admittance to the Royal Society.

Shortly thereafter he presented a paper on light and colors to the society, which caused a controversy that led to further studies on Newton's part and resulted in his corpuscular theory of light. According to this, light is the product of emission by a luminous body of a host of tiny particles traveling in empty space with a speed of about 186,000 miles per second. Newton went on to state that the corpuscles cause waves as they travel through the ether and that many optical phenomena arise from the properties of both waves and corpuscles. This explanation fell from favor in the nineteenth century, but there is a similarity between Newton's views and those of the twentieth century, in which there is a fusion of elements of both the wave and corpuscular theories of light.

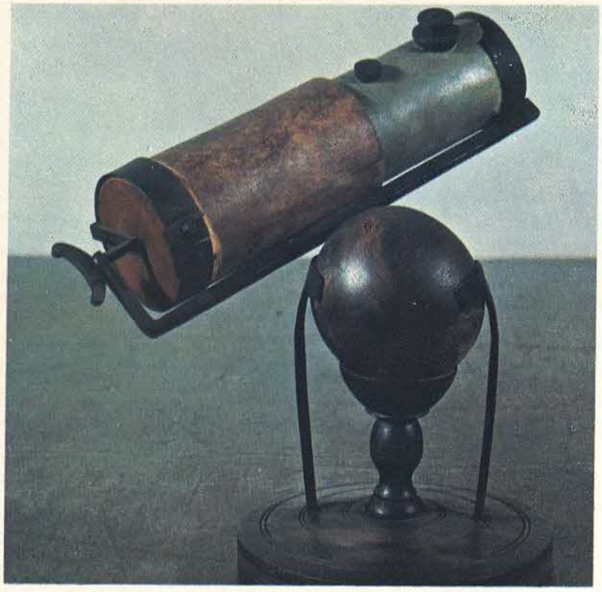
For many years Newton had also been fascinated by the main problem of motion —the force that keeps the planets moving

While at Cambridge, Sir Isaac Newton became interested in optics. Conducting experiments with prisms, he broke down a ray of light and found that white light is a mixture of all colors.

about the sun. His discovery of the law of universal gravitation has become legendary. It is said that an apple's falling from a tree in the garden where he was meditating stimulated the formation of the law. Newton never officially acknowledged this episode, but the story soon spread abroad—even the French writer Voltaire said that he had heard it from one of Newton's nieces—and the apple tree in question became a part of history.

Although Newton probably arrived quickly at an understanding that the force of attraction that is exercised between two bodies is directly proportional to the sum of their masses and inversely to the square of their distance, he decided to put off publishing the results of his studies. The law that he intuitively glimpsed was, in fact, valid for bodies that were points and had their mass concentrated at their respective centers. In the case of extended bodies, on the other hand, each of their particles would follow the same law, and Newton was not able to estimate the effect of the extended mass. It took him about twenty years before he could state the well-known theory that a spherical body of uniform density exerts the same gravitational effect as it would if all its mass were concentrated at its center.

When Edmund Halley, who was bound to Newton by deep friendship and admiration, questioned him about the trajectory of a body moving under the action of a central force that varied as the inverse square of the distance from the center, he was so struck by the depth of Newton's studies on the subject that he strongly advised him to collect in one volume all his work on gravitation and dynamics. Even though Newton's ideas on the subject had been well defined, the drafting took almost three years of uninterrupted and feverish work. Newton had no set hours of work and often spent long nights in meditation. The cost of publication was borne by Halley, and the first edition came out in 1687. The work, *Philosophiae Naturalis Principia Mathematica,* is divided into three parts: the first dealing with the principles of dynamics, the second with the motion of fluids and of bodies immersed in them, and the third with celestial dynamics. The book contains the laws of dynamics and their application to countless systems; it explains the causes of tides and gives an estimation of the mass of the moon; and starting from a knowledge of the irregular shape of the Earth, it goes on to determine the precession of the equinoxes. Knowing the velocity of rotation and the size of the planet, as well as the variation of gravitational force at different latitudes, Newton used his laws of dynamics to calculate the amount of flattening of the Earth at the poles. Only a few people immediately understood the enormous importance of Newton's work; however, the theories contained in it were soon taught at the universities, first at Cambridge in 1699 and then at Oxford in 1704.



To prevent chromatic aberration from spoiling the quality of the telescopic image, Sir Isaac Newton devised a reflecting telescope, in which the main element was a magnifying mirror.

Newton's character was not simple; though generous, modest, religious, and faithful in his friendships, he was cantankerous, irritable, and extremely introverted. Proverbially absentminded, he was not appreciated for his teaching (his lessons were often deserted), to which he gave as little time as possible. Instead, he devoted himself to his experiments, often forgetting to sleep, to eat, or to dress properly and neglecting his health to the point of a nervous breakdown that brought him to the edge of insanity in 1693. The burning of the laboratory in his house, accidently caused by his dog Diamante, drove Newton almost out of his mind.

The fame brought by his work caused him to be offered ever more important official positions, and in 1688 he was elected as the university representative to Parliament. He did not make a great impression there; in fact, his political ideas are not even known, but he was probably a moderate conservative. He never made any speeches; the only time he ever took the floor a hushed silence fell over the chamber as everyone waited for whatever words of wisdom were to come from the lips of such an illustrious scientist, but all he did was ask for a window to be closed because he felt an uncomfortable draft.

Thanks to the support of Lord Montague, afterward earl of Halifax, at that time chancellor of the exchequer, Newton became warden of the mint in 1696. He moved to a magnificent apartment in the capital, where his niece Catherine Barton, who seems to have been a close friend to Lord Halifax, acted as his hostess. If Voltaire, who was a great admirer of Newton, is to be believed, Newton got more pleasure from having a beautiful niece than from his scientific discoveries. It is certain that he was a shrewd and honest civil servant, which is further corroborated by the fact that he continued to hold his position even after Lord Halifax' death. Newton helped successfully to revise the English coinage of the period and was made master of the mint in 1699.

His official duties and the busy life of the capital contributed, without doubt, to the slowing down of his intellectual activity, fortunately at a time when he had already given voice to the best of his theories. His mind, however, remained fresh and agile in meeting the problems that still confronted him. In 1696 Johann Bernoulli challenged the mathematicians of Europe to solve the brachystochrone problem that had occupied him for a long time: the determination of the curve of most rapid descent of a particle under the influence of gravity. Newton heard about the problem on January 26, 1697, on his return from the mint, tired out after his day's work; but before retiring he had solved the problem and the following morning communicated it to the Royal Society. A problem on right-angled trajectories put forward by Gottfried Leibniz was also quickly solved by Newton, who was then seventy.

Newton was an imposing and robust old man, blessed with an iron constitution. Even though his hair had been white since he was thirty, he never lost more than one tooth throughout his life, nor did he ever wear glasses. In his old age he continued to be concerned with physics and mathematics but dedicated himself also to theology, alchemy, and cosmology—continuing his indefatigable activities until his death, when he was buried in Westminster Abbey.

NICOLLE, CHARLES JULES HENRI
(1866–1936)

The French bacteriologist Charles Nicolle was awarded the 1928 Nobel Prize in medicine or physiology for discovering that epidemic typhus fever is transmitted by the body louse. During his thirty-three years as director of the Tunis branch of the Pasteur Institute, it became a world-famous center for bacteriological research.

Nicolle was born in Rouen, France, the son of a professor of medicine. Following in his father's footsteps, he took up the study of medicine, going to Paris, where, in addition to his training at the university, he had specialized instruction in microbiology at the Pasteur Institute. After receiving his medical degree in 1893, he became a faculty member of the Rouen medical school and in 1896 was appointed director of its bacteriological laboratory.

In 1903 Nicolle was named director of the Pasteur Institute in Tunis, where he began to study the spread of typhus. He observed that typhus patients were infectious outside the hospital and upon entering and that hospital employees who admitted them also contracted the disease; yet once the patients were in the hospital and under observation, the typhus no longer spread. Deducing that the turning point came when the patients were bathed and their clothing disinfected, Nicolle realized that whatever transmitted epidemic typhus was in the clothing. He suspected the body louse; and in 1909, after experimental work with animals, he and his associates announced that the vector is, indeed, the louse, which spreads the causative organism *Rickettsia prowazetii.* Nicolle showed that the louse is infective only after taking in blood from an infected person and that biological survival is dependent upon a continuous chain of contacts.

Charles Nicolle

To combat typhus, which had long been known to spread rapidly in crowded, unsanitary conditions, Nicolle introduced strict measures; and his work was important in fighting typhus among the troops during World War I. He also demonstrated that there are instances in which no symptoms whatever appear and yet the blood is virulent on inoculation, which helped explain how contagion survives between epidemics. Later he helped clarify the distinction between the classical louse-born typhus and murine typhus, which is carried by the rat flea. His other research furthered the understanding of rinderpest, brucellosis, measles, diphtheria, scarlet fever, and tuberculosis. In addition, he founded the *Archives de l'Institut Pasteur de Tunis.*

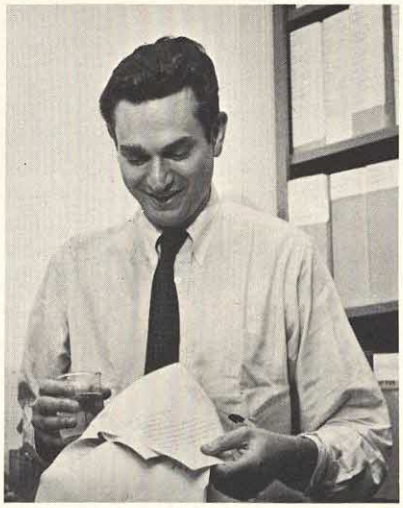
Apart from his scientific pursuits, Nicolle was a novelist and philosopher of considerable reputation. In 1932 he was elected to a chair at the Collège de France.

NIRENBERG, MARSHALL WARREN
(1927–)

For his research into the chemistry of genes, Marshall W. Nirenberg was one of three U.S. scientists who shared the 1968 Nobel Prize in medicine or physiology. He was specifically cited for breaking the genetic code. His co-winners were Robert W. Holley and Har Gobind Khorana, whose independent research confirmed Nirenberg's thesis. (*See* Robert William Holley; Har Gobind Khorana.)

Nirenberg's work started from the previously proved premise that cells carry hereditary messages through the DNA (deoxyribonucleic acid) in the chromosomes. DNA is made up of four nucleotides shaped like a double spiral, or helix, and containing simple chemicals, as well as the more complex, such as purines and pyrimidines. The configuration of a helix, and therefore its genetic message, is determined by the order in which its nucleotides are linked in combinations of threes. Nirenberg discovered that DNA does not work directly but uses an intermediary, RNA (ribonucleic acid). By demonstrating that synthetic RNA containing only one pyrimidine served as a model for creating a protein with only one amino acid, he decoded one of the three-letter combinations. He eventually discovered the codes for virtually all amino acids, which are the basic biochemical building blocks.

Nirenberg was born in New York City and received bachelor's and master's degrees in biology in 1948 and 1952, respectively, from the University of Florida. After earning a doctorate in biochemistry at the University of Michigan in 1957, he joined the National Institute of Arthritis and Metabolic Diseases and stayed there until 1962, when he was named chief of the biochemical genetics laboratory of the National Heart Institute. He was awarded both the National Medal of Science and the Research Corporation Award and was elected to both the American Academy of Arts and Sciences and the National Academy of Sciences.


Marshall Nirenberg

NOBEL, ALFRED BERNHARD
(1833–1896)

The Swedish engineer and inventor Alfred Nobel is probably best remembered as a philanthropist. Although he was the foremost creator of explosives adapted to modern warfare, he also instituted the

Nobel Foundation in order to award prizes "to those who, during the preceding year, shall have conferred the greatest benefit on mankind" in the fields of physics, chemistry, physiology or medicine, literature, and peace.

Alfred Nobel was born in Stockholm, Sweden, the youngest of three sons. After several unlucky ventures, his father, who was a brilliantly inventive man, left Sweden for St. Petersburg, Russia; and the rest of the family followed later. Delicate from his earliest youth because of a congenital weakness of the spinal column, Nobel was taught privately by tutors. At about age seventeen he was sent on travels to complete his engineering education and spent some time in the United States. On his return the family moved back to their native Sweden because of financial reversals, and Nobel took up the study of explosives, especially nitroglycerin.

This extremely powerful explosive had first been prepared in 1846 by the Italian chemist Ascanio Sobrero. Compared with the explosives that were already known, it had exceptional qualities: it released more energy than any of them on a weight-for-weight basis and had great disruptive powers. It had two drawbacks, however, one of them serious: it exploded at the slightest jarring, which made it unsuitable for both civil and military purposes; and it was liquid. Many scientists were therefore studying ways of making it easier to handle.

Despite many difficulties and setbacks, Nobel persevered in his experiments to make nitroglycerin safe. He subjected the explosive to the most varied tests to discover how to overcome the chief problem, that of transport. Nitroglycerin was transported in small glass containers carefully set in a case full of kieselguhr, which became tightly packed around the container from the jolting during transport, with the result that the latter was firmly wedged and also well cushioned. Moreover, the kieselguhr was highly absorbent and would soak up all the liquid if a container broke, thus preventing it from being spilled along the road. One day, before a loading operation, it was discovered that a glass container had cracked and that the liquid had run out into the protective powder. Nobel personally supervised the opening of the case and was struck by the solid appearance of the nitroglycerin-kieselguhr mixture. He soon found that it was much less sensitive to the impact of jolts than the nitroglycerin alone. Thus, dynamite was accidentally discovered. In 1867 it was patented in England and in the next year in the United States.

Nobel still continued his research, however. Dynamite was basically nitroglycerin made safe by its absorption by the kieselguhr, but this inert component greatly diminished its explosive power. He was therefore searching for a substance that would make nitroglycerin safe without detracting from its strength. Finally he found the solution: by combining nitroglycerin with another high explosive, guncotton, he produced a jelly-like substance called blasting gelatin, which was more powerful than dynamite.

Alfred Nobel

Although Nobel conducted research in many other areas and was the patentee of hundreds of inventions, it was the problem of explosives that absorbed him. In 1888 he developed ballistite—a powder made of nitroglycerin and nitrocellulose—which was one of the first effective smokeless propellants. An accomplishment of great importance was his construction of detonators for explosives that could not be made to explode by simple firing. These detonators contained fulminate of mercury and made it possible to set off such explosives as nitroglycerin and guncotton, which otherwise could not be used at all.

Through his inventions and his oil wells in Baku, Nobel accumulated an immense fortune, a large part of which he used to establish a foundation for the annual distribution of awards to those who had rendered the greatest services to humanity. His passion for research had made him disregard most other considerations; and when he subsequently realized that his discoveries could be disastrous for humanity if misused, he endowed the foundation in the hope that it would prove a powerful promoter of goodness, justice, and peace.

Nobel remained a controversial figure for a long time, and he was often accused of having furnished man with the most lethal means of destruction. There is a certain basis for this accusation, but it should be remembered that the explosives that he invented have made it possible to undertake vast operations for the benefit of mankind and progress. Moreover, Nobel considered them a deterrent that could effectively discourage men from warfare.

His personality was undeniably a complex one, difficult to understand, often contradictory and enigmatic. This was due largely to his physical ailments, which made him moody, often capricious and sarcastic, and a lover of solitude. He had a tremendous capacity for work and was capable of pursuing many different interests simultaneously, but his scien-

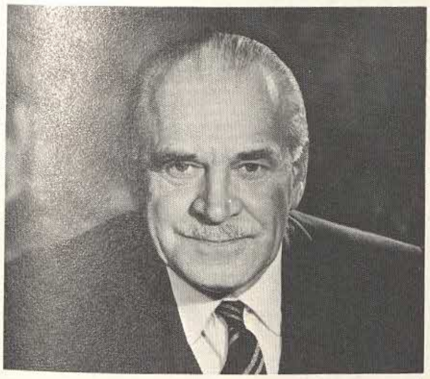
The last years of Alfred Nobel's life were spent at San Remo, Italy. His home there contained a study, where he could pursue further the subjects of interest to him.

tific and literary interests were the dominant ones. Although he had the sensibility and imaginative power of a poet, he also had a solid sense of reality and farsighted business ability.

He was considered an atheist, but he was simply opposed to dogmas. His was a desperately lonely existence; and he never knew the joys of real love, apart from that of his mother, to whom he was particularly attached. He appreciated the company of intelligent women and could be a genial and generous host, but he preferred to lead a Spartan life. In spite of his bitter pessimism, however, he always remained at heart an incurable optimist who hoped for a better world, though he himself was perhaps unable to believe in it.

NORRISH, RONALD GEORGE WREYFORTH (1897–)

The British physical chemist Ronald Norrish was one of the three European scientists who shared the 1967 Nobel Prize in chemistry. Norrish split half of the award with his research associate, the British chemist George Porter, while the other half went to the German chemist Manfred Eigen. All three were honored for "studies of extremely fast chemical reactions effected by disturbing the equilibrium by means of very short pulses of energy." Norrish and Porter were able to stop chemical reactions at intervals of almost one-thousandth of a millionth of a second and to study the progressive changes. (*See* Manfred Eigen; George Porter.)



Ronald Norrish

Norrish was born at Cambridge, England, attended the Perse Grammar School there, and did his undergraduate and doctoral work at Emmanuel College, where he also served as a research fellow. He later served as chairman of the university's physical chemistry department.

In recognition of his work, Norrish was elected a fellow of the Royal Society, an officer of both the Faraday Society and the Royal Institute of Chemistry, and an honorary member of both the Polish Chemical Society and the Polish Academy of Science. He received honorary degrees from the universities of Leeds and Sheffield. In 1958 he was awarded the Davy Medal of the Royal Society, in 1964 the Lewis Medal of the Combustion Institute, and in 1965 the Faraday Medal of the Chemical Society.

NORTHROP, JOHN HOWARD (1891–)

A pioneer in the crystallization of enzymes, John Howard Northrop, U.S. biochemist, helped establish that the once mysterious substances known as enzymes obey chemical laws. He and his colleagues isolated and crystallized several enzymes and proved them all to be proteins. For this valuable work Northrop divided one-half of the 1946 Nobel Prize in chemistry with W. M. Stanley; J. B. Sumner, whose work Northrop extended, was awarded the other half. (*See* Wendell Meredith Stanley; James Batcheller Sumner.)

Northrop was born in Yonkers, New York, and educated at Columbia University, New York City, where his father, an instructor in zoology, was killed in a laboratory explosion. He received his bachelor's degree in 1912, his master's in 1913, and his doctorate in 1915. The following year, under the direction of the experimental biologist Jacques Loeb at the Rockefeller Institute for Medical Research, he began to study theories of life duration; and in 1924 he became a member of the institute. He was named research professor of bacteriology at the University of California at Berkeley in 1949.

During World War I, when he was a captain in the U.S. Army Chemical Warfare Service, he did work on fermentation that led to his study of enzymes essential for digestion, respiration, and other life processes. After Sumner's discovery of crystalline urease, Northrop started the work that ended the controversy about whether or not enzymes are really proteinaceous. He had crystallized pepsin by 1930 and succeeded in crystallizing the enzymes trypsin and chymotrypsin in 1932 and 1935, respectively. The dozens of enzymes crystallized after Northrop's prizewinning work all proved to be proteins.

Later Northrop studied viruses and antibodies and isolated a bacteriophage—a virus that destroys bacteria. In addition, he made studies on starch, agglutination of bacteria, and the effect of temperature on insects; and in 1941 he purified diphtheria antitoxin.

Northrop was elected to the National Academy of Sciences in 1934. His *Crystalline Enzymes* appeared in 1939, and in 1948 he was coauthor of the second edition.

OBERTH, HERMANN JULIUS (1894–)

The German physicist and rocket expert Hermann Oberth was one of the founders of modern astronáutics. Early in the twentieth century he envisioned space travel as a real possibility; and independently of the U.S. scientist Robert Goddard and the Russian scientist Konstantin Tsiolkovsky, he worked out the mathematical equations necessary in building rockets for space flight.

Hermann Oberth's medical studies at the University of Munich were interrupted by World War I. After the war, he returned for a brief period but studied science and mathematics.

Oberth was born at Hermannstadt, Transylvania (now Sibiu, Rumania), the son of a physician. In 1913, at his father's request, he entered the University of Munich as a medical student; but his studies were interrupted by World War I. He served in the Austro-Hungarian infantry, was wounded, and on his recovery was assigned to an ambulance unit. This experience convinced him that he should not become a physician.

In his early youth Oberth had been impressed by Jules Verne's tales of journeys to the moon; and after the war he pursued this and other scientific interests by studying science and mathematics at the universities of Klausenburg (now Cluj, Rumania), Munich, Göttingen, and Heidelberg. At the last-named school he sought a doctorate with a thesis on space travel, but it was rejected as not being of a scholarly nature.

Oberth obtained a position as a teacher of mathematics at a school in Mediaș, Rumania, in 1924. Throughout the 1920s he conducted his own private research on rocketry, wrote books on the possibility of space travel, and even served as scientific adviser for a film about space flight. While working on a rocket that was to be used for publicity for the film, he lost the sight of his left eye as the result of an explosion.

Hermann Oberth

Taking a leave of absence from his teaching post at Mediaș, Oberth conducted research at the Reich Institute of Chemistry and Technology near Berlin and proved that liquid-fueled rocket propulsion was possible. In this work one of his assistants was Wernher von Braun.

It is not clear to what extent Oberth cooperated with the Nazis on the development of the destructive V-2 rocket. From 1938 to 1940 he worked on liquid-propelled rockets at the Technical University of Vienna and from 1940 to 1941 at the Technical University of Dresden. He was then sent to a rocket development base at Peenemünde and from 1943 to 1945 worked on solid-fueled antiaircraft rockets at another development base. Reportedly, he tried to leave Germany and go to Rumania but was forced to accept German citizenship in 1940.

At the close of the war he was placed in an internment camp and after his release was unable to obtain any kind of teaching position. He spent a year in Switzerland as a rocket consultant and in 1950 went to Italy to work on antiaircraft rockets for the Italian navy. In 1955 Von Braun invited him to work on guided missiles at the U.S. Army's Redstone Arsenal in Alabama; and he stayed there as a supervisory physicist until 1958, when he retired and returned to Germany.

OCHOA, SEVERO (1905–   )

The Spanish-U.S. physician and biochemist Severo Ochoa received the 1959 Nobel Prize in medicine or physiology for discovering the mechanism for the biosynthesis of RNA (ribonucleic acid). Ochoa's co-winner was the U.S. physician Arthur Kornberg, who made the same discovery for DNA (deoxyribonucleic acid). (*See* Arthur Kornberg.)

The work of Ochoa and others tended to confirm the idea that RNA is the chief template for protein synthesis by the cell. In certain viruses RNA is responsible not only for cell growth but also for the transfer of heredity (a function handled in most life forms by DNA). It occurs mainly in the cytoplasm but is also found, though to a lesser extent, in the nucleus of the cell. The many different types of RNA are usually broken down into three large groups: the first, or messenger-RNA, handles information on how proteins channel amino acids; while the other two, soluble-RNA and transfer-RNA, are involved in the actual protein synthesis.

Of central importance to the synthesis of RNA was the discovery of an enzyme that would serve as a catalyst. Ochoa discovered such a catalyst in 1955 and synthetically created polyribonucleotides that closely resembled RNA in structure. At the time that he received his Nobel award Ochoa expressed the hope that his work would "help to pave the way for the artificial synthesis of biologically active viral RNA and the synthesis of viruses." His work and that of Kornberg were fundamental to later studies of cell differentiation and genetics.

Ochoa was born in Luarca, Spain, and received his bachelor's degree from Málaga College in 1921 and his doctorate in medicine from the University of Madrid in 1929. From then until 1931 he was a research associate at the Kaiser Wilhelm Institute in Berlin, Germany, where he also continued his studies; and from 1932 to 1933 he worked at the National Institute of Medical Research in London, England. He returned to Spain in 1934 to teach physiology at the University of Madrid but left in 1936 because of the Spanish Civil War. For the next four years he did research at the University of Heidelberg in Germany and at Oxford University in England.

In 1940, on his arrival in the United States, he became an instructor and research assistant in pharmacology at Washington University, St. Louis, Missouri. There he had the opportunity to work under Carl and Gerty Cori, who later became Nobel laureates. The following year he joined the faculty of the medical school at New York University as a research assistant, rising to the chairmanship of the pharmacology department in 1946 and to that of the biochemistry department in 1954. He became a naturalized citizen of the United States in 1956.

OERSTED, HANS CHRISTIAN
(1777–1851)

The Danish chemist and physicist Hans Oersted was the founder of the science of electromagnetism. He was the first scientist to demonstrate experimentally the relationship between electricity and magnetism.

Although Oersted and many other scientists of his time believed that there was a connection between electricity and magnetism, it had never been proved. Oersted, who had been experimenting with electricity for some time, made the discovery in 1819 while conducting a demonstration for students. He noticed that when a compass was brought near an electric wire, the compass needle pointed in a direction at right angles to the current. The publication in 1820 of this discovery created great excitement in the scientific world. In 1934 the unit of magnetic field strength was named the oersted in his honor.

After his initial discovery, Oersted did very little work on electromagnetism; however, he made important studies on the compressibility of liquids and gases and in 1822 found a fairly accurate value for the compressibility of water. He also conducted research on thermoelectric junctions. His work in the field of chemistry included the preparation of metallic aluminum in 1825 and the discovery of piperidine in 1820.

Oersted was born at Rudköbing, Denmark, and educated at the University of Copenhagen. After receiving a degree in pharmacy in 1797 and his doctorate in 1799, he worked for a while as a chemical assistant for the medical staff at the Uni-

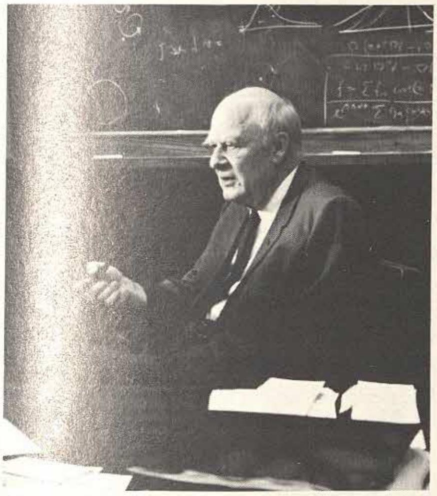
Hans Oersted

versity of Copenhagen and then spent several years traveling in Europe. In 1806 he became professor of physics at Copenhagen. He founded the Danish Society for the Promotion of Scientific Knowledge and was instrumental in the establishment of the Technical University of Denmark, becoming its first president in 1829.

ONNES. See Kamerlingh-Onnes, Heike.

ONSAGER, LARS (1903–   )

The 1968 winner of the Nobel Prize in chemistry, Norwegian-U.S. chemist Lars Onsager, developed a complex theory involving the relationships of temperature and electricity, especially as they behave dynamically. The reciprocity relation of Onsager can be used to determine how heat and voltage relate to each other in an electric conductor.



Lars Onsager

Onsager was born in Oslo, Norway, and studied at the Norwegian Technical Institute in Trondheim, receiving a degree in 1925, and at the Federal Institute of Technology in Zürich, Switzerland, before joining the staff of Johns Hopkins University, Baltimore, Maryland, in 1928. A year later he went to Brown University, Providence, Rhode Island, where he was an instructor and published his primary paper on what has been called the fourth law of thermodynamics, dealing with his theories on irreversible processes. He earned his doctorate at Yale in 1935, becoming associate professor there in 1940 and J. Willard Gibbs Professor of Theoretical Chemistry in 1945, the year he took U.S. naturalization papers.

In 1947 he was elected a member of the National Academy of Sciences, in 1953 he received the Rumford Medal of the American Academy of Arts and Sciences, and in 1958 he was given the Lorentz Medal of the Royal Netherlands Academy of Sciences. He was further honored with the Peter Debye Award in Physical Chemistry and several of the American Chemical Society's medals.

OPPENHEIMER, J. ROBERT (1904–1967)

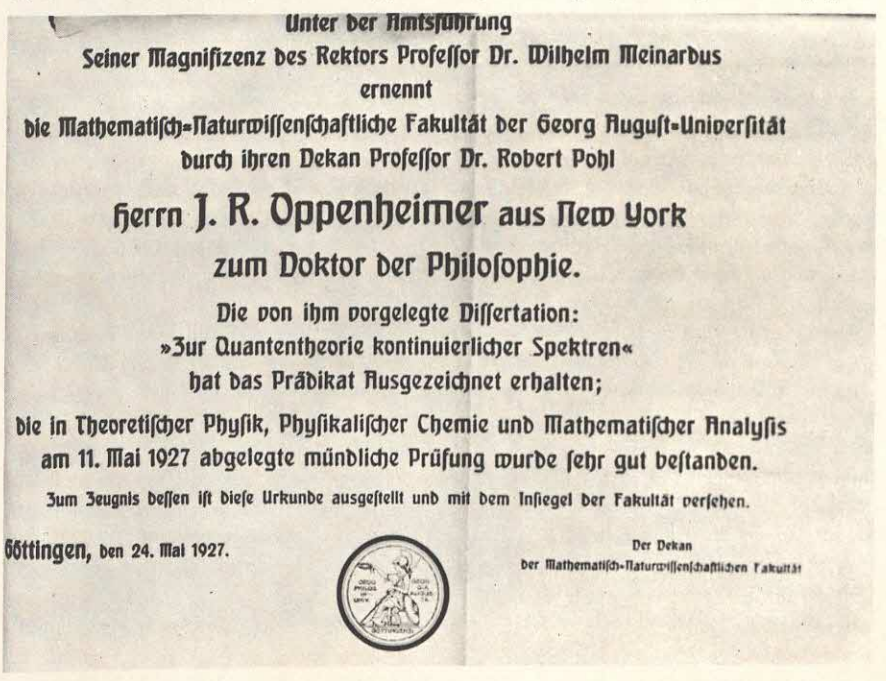
The U.S. theoretical physicist J. Robert Oppenheimer was born in New York City, the son of a German Jew who had emigrated to the United States as a boy and made a fortune in textiles. His father, being of an artistic and sensitive nature, invested a large part of his profits in a private collection of modern art that today is considered an extremely important one. Robert's mother was a gifted painter, who, although she died when he was only nine, had a strong influence on him; in particular, she encouraged in him a taste for art and literature. This parental influence would not have been so important had he not already had a naturally wide range of interests, the scope and variety of which are evident from the fact that while still a young boy he had assembled a large collection of minerals and written a treatise on light. Because of delicate health, his childhood was a solitary one; but far from idling his time away, he studied nine languages, including Sanskrit and Chinese, along with his regular lessons.

The precociousness that he showed at such an early age was only the prelude to an equal facility in learning the science to which he was to dedicate his life: physics. At age eighteen he went to Harvard University and graduated with honors after only three years, in 1925.

To mark the occasion, his father gave him an exceptional present: a thirty-foot sailboat to provide relaxation from his studies. In this frail craft he sailed across the Atlantic Ocean to England. He had shown himself to be a good sportsman, but the aim of the voyage was not only sport. As soon as he reached port, he set out to visit the English research centers, which at that time were much more famous than their U.S. counterparts. At Cambridge, for instance, there was Lord Ernest Rutherford, whose laboratory Oppenheimer started to frequent. He soon attracted attention there because of a characteristic rare in physicists: an aptitude for experimental work, as well as for theoretical research.

While at Cambridge, he was invited by Max Born, one of the most famous theoretical physicists in Europe, to Göttingen, which was then a center of intense scientific activity and offered an environment that satisfied his desire both to learn and to assert himself. He had always had an innate need to be liked, which expressed itself in a strange, captivating charm that was to prove both a strength and a weakness. He received a doctorate from Göttingen in 1927, and after two years of further study at Zürich and Leiden he returned to the United States. Unfortunately, however, he was soon found to have incipient tuberculosis and convalesced on a ranch that his father bought for him on the Alamogordo Desert, near Los Alamos, New Mexico.

In 1927, with his thesis "On the Quantum Theory of Continuous Spectra," J. Robert Oppenheimer received a doctorate from the University of Göttingen, a leading center of physics.



Unter der Amtsführung
Seiner Magnifizenz des Rektors Profeſſor Dr. Wilhelm Meinardus
ernennt
die Mathematiſch-Naturwiſſenſchaftliche Fakultät der Georg Auguſt-Univerſität
durch ihren Dekan Profeſſor Dr. Robert Pohl

Herrn J. R. Oppenheimer aus New York
zum Doktor der Philoſophie.

Die von ihm vorgelegte Diſſertation:
»Zur Quantentheorie kontinuierlicher Spektren«
hat das Prädikat Ausgezeichnet erhalten;

die in Theoretiſcher Phyſik, Phyſikaliſcher Chemie und Mathematiſcher Analyſis
am 11. Mai 1927 abgelegte mündliche Prüfung wurde ſehr gut beſtanden.

Zum Zeugnis deſſen iſt dieſe Urkunde ausgeſtellt und mit dem Inſiegel der Fakultät verſehen.

Göttingen, den 24. Mai 1927.

Der Dekan
der Mathematiſch-Naturwiſſenſchaftlichen Fakultät

From among the many teaching possibilities offered him, he chose the chair at the University of California at Berkeley "because," as he paradoxically told the dean, "of the collection of French poets in your library." At the same time he also taught at the California Institute of Technology, Pasadena. Often his pupils, intrigued by his careless charm, imitated his idiosyncracies: he smoked a pipe uninterruptedly, dressed with careful casualness, and punctuated conversations with bursts of coughing, long silences, and sibylline replies. This austere and rather snobbish scientist spent most of his time in study, and even his hobbies were studious ones. He did not read the newspapers or listen to, or even own, a radio. It is said that he did not know about the 1929 crisis until a year later, since the thing did not concern him; and he showed the same lack of interest in politics.

J. Robert Oppenheimer

In 1937 the news of the racial persecutions and the Spanish Civil War revived his interest in the lives of others and in human suffering. It was during this period that he shook off his indifference for political problems and aided left-wing causes. By 1940, however, when he married the biologist Katherine Harrison, his opinions were changing, chiefly because of the accounts of scientists who had come back from the Soviet Union and because of that country's ambiguous policy during the first phase of World War II.

During this time Oppenheimer had a great influence on the development of physics. His contributions included the quantum theory of electrons and positrons, the theory of cosmic rays, and the theory of nuclear structure. At the outbreak of World War II, studies in these areas were already well ahead in Germany; and suddenly many of the physicists who had been working on them disappeared from circulation. This fact, combined with information about the buying up of certain materials, suggested that Germany was secretly working on the construction of nuclear weapons. These arms were the direct result of the discovery of nuclear fission. Since Anglo-American scientists were convinced that research on such weapons was already far advanced in Germany, they advised the U.S. government of the need to undertake studies for the development of the same weapons.

One of these scientists was Oppenheimer, and in 1943 he was appointed director of the Los Alamos Laboratory near Santa Fe, New Mexico. With his engaging personality and his powers of persuasion, he inspired hundreds of scientists to abandon their academic positions, interesting research, and regular lives in order to live in huts and carry out secret research for military purposes. This venture, officially known as the Manhattan Project, culminated two years later, at Alamogordo, New Mexico, in the first atomic bomb explosion.

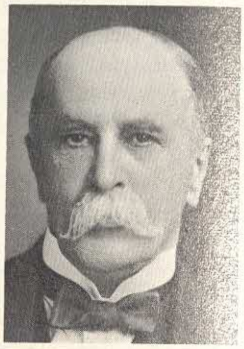
After the war, in addition to his work as director of the Institute for Advanced Study, Princeton, New Jersey, from 1947 to 1966, he served on various government committees, including the General Advisory Committee of the U.S. Atomic Energy Commission, of which he was chairman. In these capacities he took an active part in the further development of atomic energy and in the question about its possible consequences. In 1954, however, despite the favorable evidence given by his colleagues, he was declared to be a potential danger to the country and had his government security clearance withdrawn. Thereafter he continued to write and to serve as director of the Institute for Advanced Study until his retirement. He was awarded the Fermi Prize by the U.S. Atomic Energy Commission in 1963.

OSLER, SIR WILLIAM (1849–1919)

The British physician Sir William Osler was one of the best-known teachers of medicine, and his detail and writing style made his books among the most readable by physicians. Osler has been described as unsurpassed as an inspiration to medical students.

He was born at Bond Head in Ontario, Canada, and educated at the University of Toronto and at McGill University in Montreal. After receiving his medical degree from the latter school in 1872, he was a professor of medicine successively at McGill (1874–1884), Pennsylvania (1884–1889), Johns Hopkins (1889–1904), and Oxford (1904–1919) universities.

His book *The Principles and Practice of Medicine* was the most popular medical textbook from the time it was first published in 1892 until long after his death. Medical scholars still consider Osler one of the finest and most dedicated teachers and physicians of his time. He made many clinical discoveries and conducted numerous studies on diseases of the heart and blood.



Sir William Osler

Osler was created a baronet in 1911. Among his other published works are *Aequanimitas* (1904), *An Alabama Student* (1908), *Chorea and Choreiform Affections* (1894), *Angina Pectoris and Allied States* (1897), and *The Diagnosis of Abdominal Tumors* (1901).

OSTWALD, FRIEDRICH WILHELM
(1853–1932)

One of the scientists who laid the basic groundwork of modern physical chemistry was the German chemist Friedrich Ostwald. He did important research in all areas of the new physical-chemical science, but it was mainly for his work in defining the role of a catalyst that he was awarded the 1909 Nobel Prize in chemistry.

Inspired by the work of Svante Arrhenius, Ostwald early in his career became interested in electrochemistry and did much to publicize the views of Arrhenius. With another friend, Jacobus van't Hoff,

Friedrich Ostwald (Also, see photograph, p. 91.)

he established the first journal of physical chemistry in 1887; and in 1888 he stated what is known as the Ostwald law of the dilution of an electrolyte. He also did research on the conductivity of organic acids.

In 1894 Ostwald presented his definition of catalysis, stating that catalysts speed the rate of a chemical reaction without otherwise interfering with the substances involved. This had important applications in industrial chemistry. Ostwald also devised a method for commercially producing nitric acid by the catalytic conversion of ammonia.

He was born in Riga, Latvia, and studied chemistry at the University of Dorpat in what is now Estonia, receiving his doctorate in 1878. After spending some time teaching at a high school, he was appointed professor of chemistry at the University of Riga in 1881. From 1887 to 1906 he was a professor at the University of Leipzig in Germany. Poor health, however, forced him to retire from the academic world to his country estate near Leipzig, and from then until his death he devoted his time to philosophical questions and also worked on a new theory of color. An energist, believing that chemical studies should be limited to measurable phenomena, he was one of the last scientists to accept the atomic theory.

OWEN, SIR RICHARD (1804–1892)

The British biologist Sir Richard Owen was a pioneer in vertebrate paleontology and a prolific writer on comparative anatomy. He was also instrumental in setting up a national collection of natural history in London.

He was born in Lancaster. At age sixteen he was apprenticed to a surgeon and in 1824 went to the University of Edinburgh to study medicine. After obtaining his medical degree at St. Bartholomew's Hospital in London and practicing medicine for a short time, he became assistant to the conservator of the museum of the Royal College of Surgeons. In 1836 he was appointed professor at the Royal College, in 1849 he became the museum's conservator, and in 1856 he was named head of the natural history department of the British Museum. In the last-named position he was successful in obtaining a new building to house the museum's natural history collection separately in South Kensington, London. He remained in this post until 1884, when he was knighted and retired to Richmond Park.

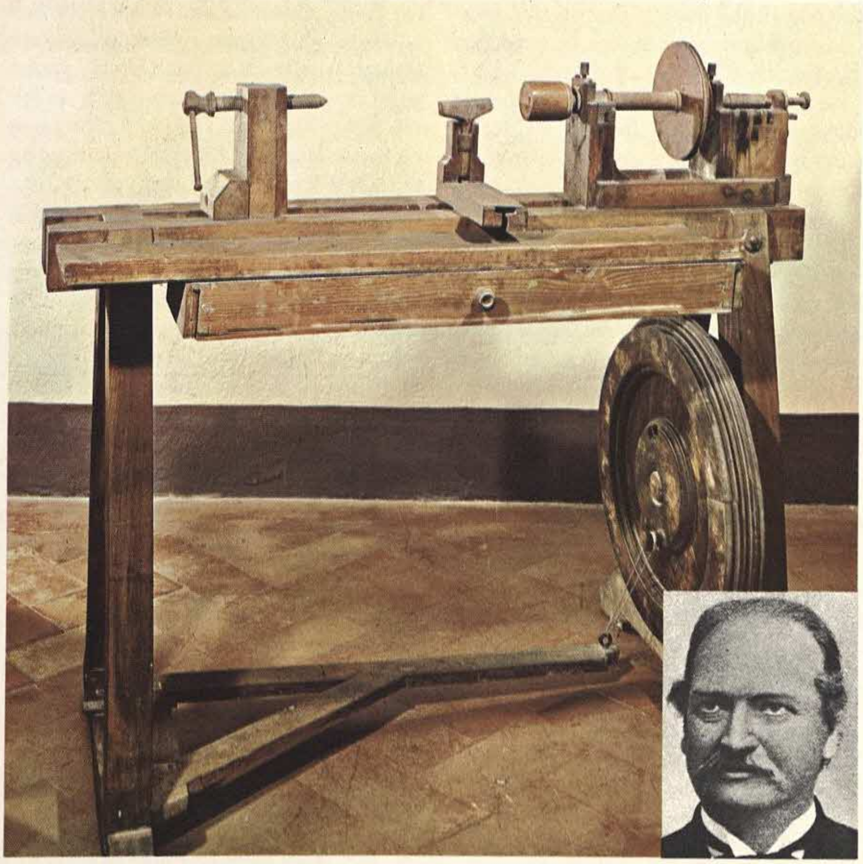
Memoir on the Pearly Nautilus (1832) was the first of many noteworthy publications by Owen. For almost fifty years he devoted his time to comparative anatomy, especially that relating to extinct animals and birds. He was very industrious, but, unfortunately, his works contain a number of errors.

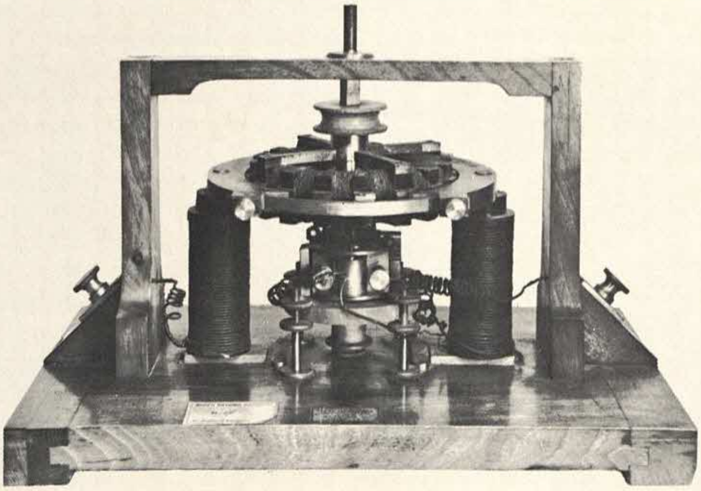
Among his other notable works are *Odontography* (1840–1845), *A History of British Fossil Mammals and Birds* (1846), *The Archetype and Homologies of the Vertebrate Skeleton* (1848), *History of British Fossil Reptiles* (1849–1884), *Comparative Anatomy and Physiology of Vertebrates* (1866–1868), *Monograph of the Fossil Mammalia of the Mesozoic Formations* (1871), *Catalogue of the Fossil Reptilia of South Africa* (1876), and *Antiquity of Man as Deduced from the Discovery of a Human Skeleton* (1884).

PACINOTTI, ANTONIO (1841–1912)

The Italian physicist and inventor Antonio Pacinotti is remembered chiefly for his invention, in 1860, of a dynamo with ring winding. He was also the first scientist to construct direct-current induction motors, in which he used metal rollers instead of brushes. In 1859 he built a model of an electromotor. Another of his accomplishments was introducing the first generator into use in Bologna.

Using a lathe, among other tools, the Italian physicist and inventor Antonio Pacinotti carefully and patiently constructed an early electric motor.





Pacinotti was born in Pisa, Italy, and received his education at the university there. In 1862 he took up a post as an astronomer at Florence and two years later moved to Bologna, where he accepted a professorship at the university. He became professor at the University of Cagliari in 1873 and then returned to the University of Pisa as professor of physics in 1882.

PAPPUS (about A.D. 320)

Pappus of Alexandria was a Greek geometer who lived at Alexandria, the great seat of scientific learning. The only evidence as to the time he lived is the references to a solar eclipse in a commentary he wrote on Ptolemy's *Almagest*.

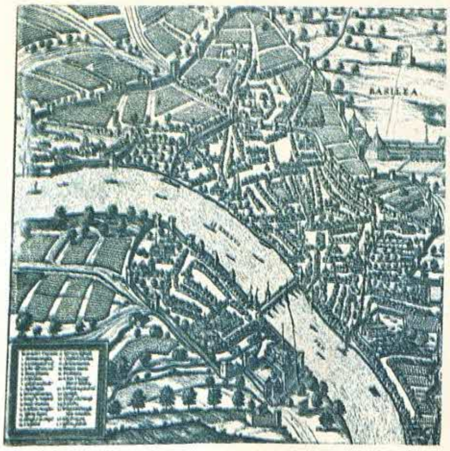
He is known for his great work of eight books called simply *Collection*, written in about A.D. 340. It is a major source of all present knowledge of ancient Greek mathematics. Only an incomplete form of the entire work survives. The first book apparently was lost, and others have been damaged by time. From what is extant of the work, it appears to have included the most important mathematical advances up to Pappus' time. It contains problems and theorems of plane and solid geometry, as well as descriptions of mechanics and astronomy.

PARACELSUS (1493–1541)

The Swiss physician and alchemist Paracelsus was a precursor of Galileo. He was born Theophrastus Bombastus von Hohenheim; but while a medical student in Basel, he decided to adopt the name Paracelsus either to indicate his superiority over the Latin medical writer Celsus or, more probably, simply to Latinize his name (the German *Hohenheim* means "high dwelling").

Medicine at the time of Paracelsus was still a pseudoscience, composed chiefly of misconceptions, vitalistic notions, and alchemy mixed with false theories and fetishistic superstitions. The alchemists for their part carried on a long and fruitless search for a universal panacea, the elixir of life, and the philosophers' stone, which reputedly could transform base metals into gold. It was an era of collective gold psychosis, induced by a real economic need, which was particularly acute in the German states, where there were much minting of coins and a smaller supply of precious metals than in the rest of western Europe.

Paracelsus studied medicine at Basel, Switzerland, and later taught at the university there.



Paracelsus was a strange and rebellious boy, quite unlike his father, Wilhelm von Hohenheim, a dedicated doctor, who was the descendant of a family of feudatory nobles. Wilhelm was a mild and solitary man who, after the death of his young wife, devoted himself completely to his son and to his work. The child grew up in his native village of Einsiedeln, in the canton of Schwyz, alone with his father, whom he followed in wanderings through the woods, developing at a very early age the love of nature that was to remain one of his outstanding characteristics. In 1502 they moved to Villach, in Carinthia, where the father had the double function of giving medical treatment to the miners and teaching chemistry in the school attached to the mines.

After attending the Benedictine school at Lavanthal, Paracelsus continued his studies in Basel. He was a moody student who, for the most part, avoided his classmates. This psychological need for solitude led Paracelsus to abandon his regular studies and retire to Würzburg as the disciple of an eccentric scholar and abbot known as Trithemius, who taught him the basic principles of alchemy and the occult sciences. By 1515 he was a changed man, full of an insatiable desire to learn. In the ten years that followed, he traveled incessantly, heedless of the uncomfortable means of transport and the troubled times, journeying all through Europe, from England to the most eastern regions. Wherever he went he collected new prescriptions, tried unknown medicines, and, above all, observed nature.

After a military interlude, when he took part in the war of the Netherlands as a surgeon, he settled in Strasbourg for a time and then moved on to Tübingen and Freiburg, where he practiced medicine. The fact that he was a member of the merchants' and millers' guilds and not those of the doctors and apothecaries would seem to confirm the accusation leveled at him by adversaries that he had no degree.

Paracel

He was extremely successful, howe and his fame reached Basel, where was summoned by Erasmus of Rotterd to treat the printer Frobenius for wh seemed to be an incurable fracture. Pa celsus lived up to his reputation an thanks to the influence of Erasmus, wh held a position of particular authority i the European cultural world at that time, succeeded in obtaining a chair at the university. This should have finally brought him security, but he seemed to constantly alienate associates with his biting tongu and even more biting pen, his noncon formist behavior, and his contempt for tradition.

The students were enthusiastic abo this badly dressed professor who trigued them with experiments and provised lessons given in German rat than in Latin; but this enthusiasm was little help to him. Nor was the patien gratitude to this ill-tempered doctor, wh cured them with strange and unheard methods, of more avail.

Part of his method was a mania fo cleanliness; it is impossible to establis today whether he clearly recognized the need for what came to be known as asepsis or whether he managed to reduce the number of infections and the contagiousness of diseases accidently as a side effect of his compulsiveness. It is certain, however, that he had divined the right way.

He also had the merit of realizing that medicine had to become an experimental science. At that time, doctors frequently had recourse to magic for their prescriptions and methods of treatment; for example, to treat a wound it was also necessary to treat the sword that caused it. Such practices struck Paracelsus as monstrous, and he therefore turned his efforts to combating them and working for their elimination. For this reason he championed the experimental method.

Paracelsus was firmly convinced that the human body and life were the result of chemical reactions and that the secrets of the workings of the body should therefore be sought in chemistry. He was aware that alchemy was thoroughly discredited and that consequently it would be difficult to win acceptance for its methods in the search for medicines. He knew, however, that he was on the right track, and this gave him the strength to fight and to uphold his thesis in the face of difficulties.

He himself prepared the medicines with which he treated his patients, and he usually distributed them free. His patients were so numerous that his popularity seriously affected the chemists who lived from the sale of extremely complicated prescriptions drawn up by the other doctors of the time. Thus, he antagonized apothecaries and doctors, as well as the professors of the university. Because they could not combat Paracelsus on scientific ground, they resorted to intrigue and slander. Paracelsus was, in fact, not above reproach, and he often roamed drunk around the town. When he had the audacity to incite the students to burn the works of Avicenna and Galen in 1527, his colleagues' animosity reached its peak and they persuaded the Basel authorities to expel him from the town on a charge of depravity and blasphemy.

Embittered, Paracelsus took refuge in Colmar, where he set up a laboratory in a cellar and continued his experiments and resumed his writing. He was increasingly attracted by occult sciences, astrology, and, finally, religion. He even abandoned his medical practice in order to devote himself to spreading God's word among the mountain inhabitants of Appenzell from 1531 to 1534. From there he went to Innsbruck and then to the Tirol, to Engadine, and finally to Vienna.

A brief period of peace and contentment followed, during which he returned to Villach to see his father. For yet another affront to official science, however, he was obliged to leave once more and to resume his wanderings. In 1541 he was in Salzburg, where the bishop, Prince Ernst of Bavaria, had granted him protection and where, soon afterward, he died under mysterious circumstances, undoubtedly alone and penniless.

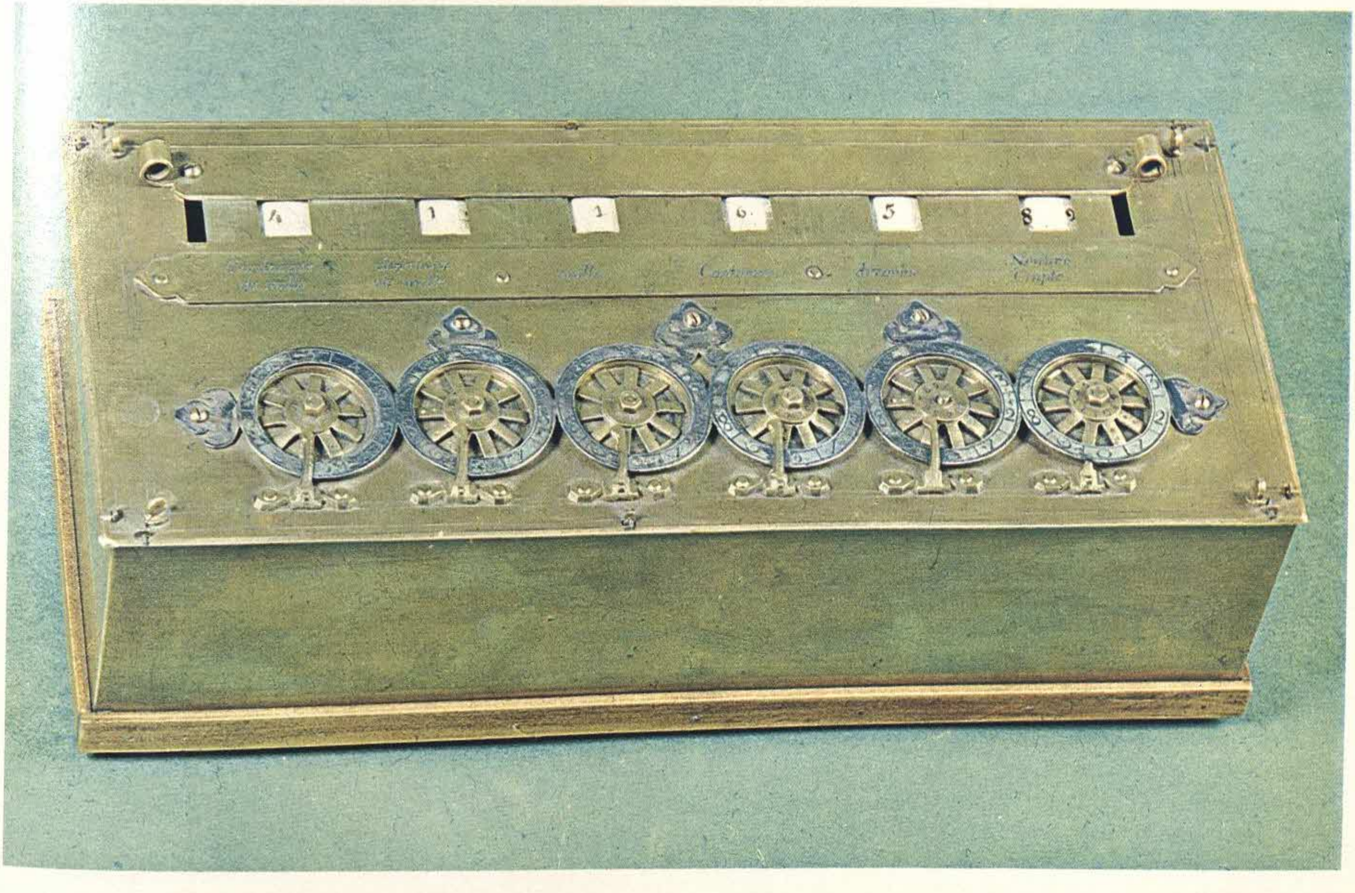
PASCAL, BLAISE (1623–1662)

One of the most talented men of the fifteenth century was the French mathematician, physicist, and philosopher Blaise Pascal. Deeply and sometimes fanatically religious, he tried to reconcile the rational and the mystical. This personal conflict helped him to success in the field of literature and philosophy but prevented him from making full use of his abilities as a scientist. Nevertheless, he made important contributions to mathematics, particularly in the field of geometry.

Pascal was born at Clermont-Ferrand, France, to a prosperous middle-class family. His father, Étienne, a magistrate greatly respected for his moral uprightness, gave his son a strict education. The young Pascal was also influenced by his two sisters, who alleviated some of the harshness of the father's teaching. It was the influence of his family that gave rise to the rigorous reasoning that was the keynote of Pascal's scientific and philosophical thoughts.

When he was but twelve years of age, he read Euclid's *Elements* and immediately grasped the sense of the work. He understood the fundamental geometric theorems; and following the reasoning of the famous Greek, he was able to reconstruct the logical development of geometry. During those years the Cartesian approach to geometry was becoming popular. This consisted of turning geometric problems into algebra by assigning numbers to the points of the geometric figures. With the Cartesian method the properties of the figures were dis-

To help his father in his administrative duties at Rouen, France, Blaise Pascal devised an adding machine that was designed not only for long calculations but also for very complex ones. It used a wheel method for reporting calculations automatically. Basically the same in principle as modern business machines, it made the present structure of computers possible. Pascal spent a number of years in the construction and perfection of similar adding machines and procured a patent to protect himself from competition.



covered by calculation rather than by reasoning. Pascal rejected this method and always kept to generalized reasoning; that is, deducing the properties of the figures themselves. This enabled him to tackle several of the most difficult theorems in the then new projective branch of geometry. In particular, he was interested in the theorems regarding the properties of conic sections, on which he wrote a treatise at age sixteen, becoming the center of attention among the scholars of the time.

When his father obtained an important administrative post at Rouen from Cardinal Richelieu that involved making many long, difficult calculations, Pascal, convinced that calculation could be mechanized in a more practical way than by using an abacus, decided to help his father by making a device that was basically the same in principle as modern business machines. He introduced the use of the wheel for carrying forward numbers in mechanical calculation and completed the working model of the machine when he was twenty-one years of age. This invention made the present structure of modern computers possible, but more than a century was to pass before such machines were made for mass distribution.

Pascal relied heavily on direct experimentation, and he decided to solve fundamental problems about which scientists could not agree. Some scientists wanted to refute Evangelista Torricelli's experiment, maintaining that the barometric vacuum could not exist. They believed that what appeared above the column of mercury in the barometer was nothing but rarefied air. Pascal refuted the rarefied air theory, and this brought him into the difficult area of the mechanics of fluids. He was able, however, to formulate the famous principle of the constancy of the transmission of pressure inside liquids.

His father's fall from a horse in 1646 was a decisive event: two Jansenists with ideas of religious reform entered the family circle as surgeons. The ascetic Jansenist ideal fired the young Pascal; and his health, which was poor already, became worse because of overwork and because of the penances that he practiced. At doctors' suggestions that he lead a life more fitting for a young man of twenty-eight, he again turned to more worldly pursuits. The most important problems for him became scientific ones, and this was the most profitable time for his studies on combinatorial analysis and the calculus of probability. These two important branches of mathematics required a logical mind, and Pascal contributed notably to them.

Blaise Pascal

After a short time he had another mystical crisis and was convinced that he had to withdraw from the world and live with the scholars at Port Royal. His health became worse and worse. Without losing his courage, however, he wrote the *Provincials*, eighteen violently polemical letters in defense of the Jansenist movement, for which he risked being condemned by the pope. He also wrote on the cycloid, the curve generated by the rotation of a point placed on the periphery of a rolling circle. In 1658 he published, under the pseudonym of Amos Dattonville, a series of problems on the squaring of the cycloid, challenging other mathematicians to find the solutions he had obviously reached. These were his last scientific works. His last years were spent in physical suffering and religious preoccupations.

PASTEUR, LOUIS (1822–1895)

The word *pasteurized*, appearing on containers of milk and some other beverages, is a daily reminder of the work on fermentation done by the French biologist and chemist Louis Pasteur, who developed pasteurization, a process of partial sterilization of certain perishable foods by heat. He also did important research on infectious diseases and is particularly noted for developing a vaccine for rabies.

Pasteur began his studies on fermentation in 1856 when he was asked to find a way of preventing beer and wine from souring, since spoilage had been causing great losses and was endangering the beer and wine industries of France. Using a microscope, he examined the yeast in good and sour beer and wine and found that the yeast globules in the good beer and wine were round, while those in the sour beer and wine were elongated. He concluded that there are two types of yeast—one producing alcohol, and the other, lactic acid.

During the course of these investigations, Pasteur demonstrated that fermentation is caused, not by chemical decay, as had been previously believed, but by microorganisms in the yeast and that certain types of microorganisms are needed for proper fermentation to take place. He found that heating beer and wine before setting them aside to age would kill any remaining yeast, including the lactic acid one, and therefore prevent souring. This process came to be known as pasteurization and is widely used today in the food industry.

Pasteur's discovery that fermentation is caused by microorganisms carried in the air formed the basis for Joseph Lister's work on antiseptic surgery and led Pasteur himself to the question of spontaneous generation, which at that time was having a revival. By a series of elaborate experiments he demonstrated that microorganisms do not grow in filtered, sterile air, proving beyond doubt that there is no such thing as spontaneous generation.

Famous for his solution to the problem of the French beer and wine industries, Pasteur was then asked to investigate a disease of silkworms that was threatening the French silk industry. In 1865 he found two bacilli responsible for two types of disease in silkworms and recommended separating the healthy from the diseased worms and killing the latter, thereby bringing the infection under control and saving the French silk industry.

Some of Pasteur's most brilliant work was in the field of communicable diseases. He developed the so-called germ

With the aid of a microscope, Louis Pasteur pioneered in bacteriology. In 1865 he found the organisms responsible for disease in silkworms and helped save the silk industry.

Louis Pasteur

theory and devoted many years to isolating the organisms responsible for such diseases as anthrax, chicken cholera, swine erysipelas, and rabies. He found that he could inoculate animals against anthrax and chicken cholera by using attenuated organisms—disease-causing organisms whose virulence had been reduced—and that anthrax germs could be attenuated by heating. In 1881 he successfully demonstrated his method of immunization against anthrax by inoculating sheep with attenuated anthrax germs, and he had similar success with chicken cholera germs.

Rabies, however, presented a more difficult problem. Since a rabies germ could not be located under the microscope, it could not be isolated for preparation in cultures, which had been Pasteur's method for finding ways of attenuating the other disease germs. Correctly assuming that the organism existed but was too small to be seen through his microscope, Pasteur proceeded to cultivate it in live animals and devised an ingenious way of attenuating it. After discovering that the disease attacks the spine, he removed the spinal cords of infected rabbits, stored them in sterile air, and from this material prepared a vaccine that could prevent rabies in dogs.

The rabies vaccine also proved valuable as a treatment. In 1885 Pasteur successfully inoculated a young boy, Joseph Meister, who had been bitten by a rabid dog. This life-saving treatment for rabies, or hydrophobia as it is known in man, brought Pasteur worldwide fame and in 1888 led to the founding, by public subscription, of the Pasteur Institute to promote further research on rabies. (During the Nazi invasion of France in World War II, Meister was working as a gatekeeper at the institute; and rather than comply with the Nazis' demand that he open Pasteur's tomb, he committed suicide.)

In addition to his pioneering work in bacteriology, Pasteur made a major contribution to chemistry. He was one of the first investigators in the field of stereochemistry and found that racemic acid is composed of a mixture of two optically different forms of tartaric acid crystals.

Pasteur was born at Dôle, France, and received his education at the Royal College of Besançon and the École Normale in Paris. He wished to become a professor of fine arts and was considered a mediocre student in chemistry until he was inspired by the lectures of the noted chemist Jean Baptiste André Dumas. In 1848 Pasteur was appointed professor of physics at Dijon and a year later became a professor of chemistry at the University of Strasbourg. From 1854 to 1857 he was professor of chemistry and dean of the science faculty at the University of Lille. He became director of scientific studies at the École Normale in 1857 and remained there until 1863, when he was appointed professor of geology, physics, and chemistry at the École des Beaux-Arts in Paris. After serving as professor at the Sorbonne from 1867, he became head of the Pasteur Institute on its founding in 1888 and spent the rest of his life in that capacity.

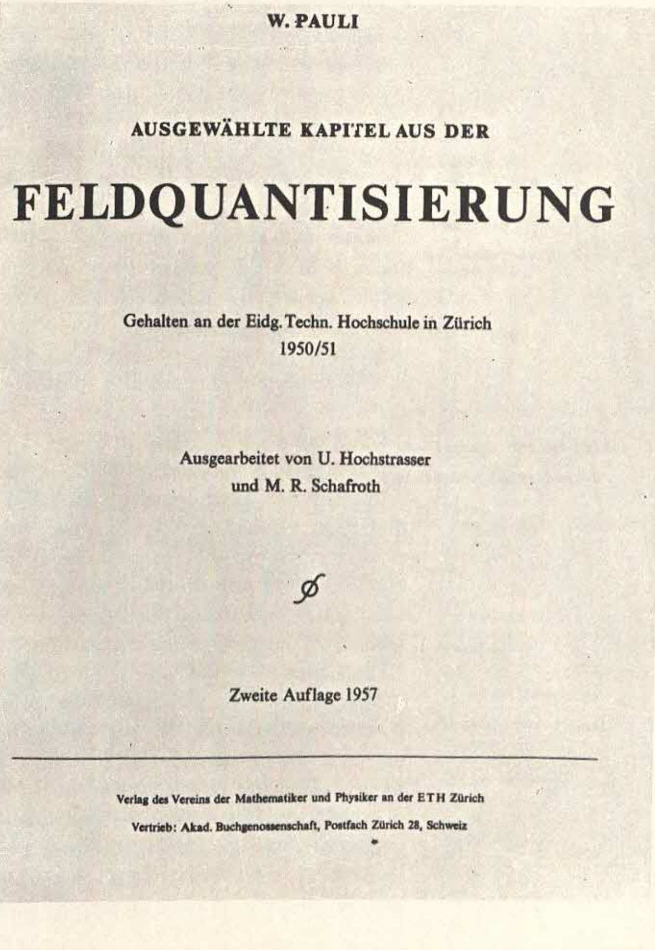
Pasteur's contributions to science were widely recognized during his lifetime. For his work on stereochemistry he was awarded the Rumford Medal of the Royal Society. After using his prestige and influence to pressure French physicians into adopting sterile procedures, he was made a member of the French Academy of Medicine in 1873. He was elected a member of the Academy of Sciences in 1862 and a member of the French Academy in 1881.

PAULI, WOLFGANG ERNST
(1900–1958)

The Swiss physicist Wolfgang Pauli formulated the Pauli exclusion principle, which states that two electrons in an atom cannot exist in the same state. For this discovery he was awarded the 1945 Nobel Prize in physics.

Pauli was born in Vienna, Austria, son of a physical chemistry professor. He studied physics under Arnold Sommerfeld at the University of Munich, Germany, where he received his doctorate in 1921, and then served as assistant to Max Born at the University of Göttingen, Germany, and to Niels Bohr at the University of Copenhagen, Denmark. In 1923 he joined the faculty of the University of Hamburg, staying there until 1928, when he became professor of theoretical phys-

The Swiss physicist Wolfgang Pauli not only was instrumental in the development of the quantum theory but, through his publications, also decisively influenced its evolution.


W. PAULI

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Wolfgang Pauli

ics at the Federal Institute of Technology in Zürich, Switzerland.

Pauli announced his exclusion principle in 1925 as he was attempting to explain an idea known as the anomalous Zeeman effect. Bohr and Sommerfeld earlier had worked out energy levels of electrons with hydrogen atoms, which could be expressed as three quantum numbers. This theory, however, did not explain the anomalous Zeeman effect; and in trying to explain it, Pauli concluded that another quantum number must exist. The exclusion principle is a fundamental factor in the structure of matter and is essential in describing atomic nuclei properties and the electrical conductivity in metals. Pauli's *Collected Scientific Papers* was published in 1964.

PAULING, LINUS CARL (1901–)

The first person ever to win two full Nobel Prizes was the U.S. chemist Linus Pauling. For discovering the principles governing chemical bonds and the structure of molecules, he was awarded the 1954 Nobel Prize in chemistry; and for his efforts directed toward encouraging the cessation of all nuclear-bomb testing, he was awarded the 1962 Nobel Peace Prize.

Linus Pauling

Pauling was born in Portland, Oregon, and in 1922 earned a degree in chemical engineering at Oregon State College. Three years later he received his doctorate in chemistry from the California Institute of Technology, Pasadena, where he had already begun working in 1922 and where his entire career was centered: as research fellow (1925–1927); assistant professor of chemistry (1927–1929); associate professor (1929–1931); professor (from 1931); and director of the Gates and Crellin Laboratories of Chemistry (1936–1958). He was elected to the U.S. National Academy of Sciences in 1933.

In his research, he first concerned himself with applying quantum mechanics to chemistry and worked out a comprehensive explanation for chemical bonds based on the theory that electrons join up in pairs. These studies resulted in the discovery of such fundamental principles as directed valence and the hybridization of bond orbitals, the partially ionic nature of single bonds, and the effect of resonance on molecules.

During the mid-1930s Pauling became interested in the study of protein molecules and advanced the idea that they are in the shape of a helix, being the first scientist to construct an accurate model of a protein molecule. Through his studies of hemoglobin molecules, he found that sickle-cell anemia is a hereditary molecular disease. He also worked out a theory of how general anesthesia is induced through molecular action.

PAVLOV, IVAN PETROVICH

(1849–1936)

The Russian physiologist Ivan Pavlov became famous for his work in the physiology of digestion, for which he was awarded the Nobel Prize in physiology or medicine in 1904. His interest in the neural aspects of digestion led him to research on the formation of the conditioned reflex, work which proved to be more important than that for which he received the Nobel Prize.

Pavlov's work in digestion was manifold. He discovered the secretory nerves to the pancreas in 1888. Through the device of the gastric pouch, he was able to observe the effects of sham feeding on dogs. The gastric pouch received food intended for the dog's stomach; Pavlov could show that since the animal's gastric juices would flow nonetheless, another factor, namely the stimulation of nerves in the mouth by food, caused the secretion. In like ways he demonstrated that the sight or smell of food also stimulated gastric flow, indicating the presence of a psychic factor.

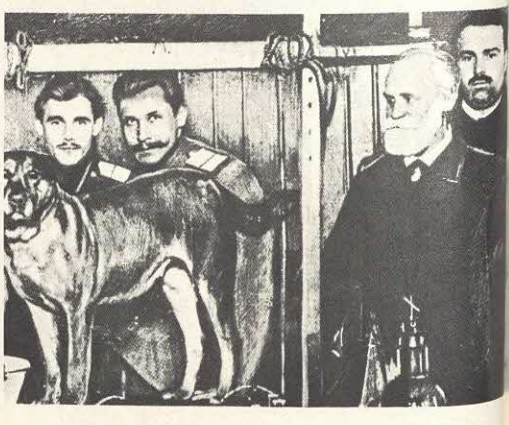
Having determined the place of the vagus nerve in gastric activity and shown that gastric juice acidity remained constant, Pavlov posited three phases of digestion. These were nervous, pyloric, and intestinal. It was these conclusions on digestion for which he was awarded the Nobel Prize.

Pavlov's work on the conditioned reflex grew in part out of I. M. Sechenov's theory of brain reflexes. Sechenov held that mental phenomena were based on physiological processes, just as nervous activity was known to be. This constituted a rejection of mind-body dualism, which Pavlov thought was inherent in traditional psychology. Food placed in a dog's mouth will cause the flow of gastric juice. This Pavlov considered an unconditioned response. He was able to demonstrate that the animal can be conditioned to another stimulus that will elicit the same apparent response. In a now famous experiment Pavlov rang a bell each time food was placed in a dog's mouth, the animal came to associate food and the bell sound and was conditioned to produce gastric flow at the sound of the bell, even in the absence of food. Pavlov tried to explain higher mental processes, such as that of language in humans, with his theory of conditioned reflexes that grew out of these experiments. There is, however, no valid proof for his hypotheses.

The methods used by Pavlov in con-

The opening remarks at the first meeting of the XV Congress of Physiologists were made by the Russian scientist Ivan Pavlov, who was known for his work relating to the digestive processes.

Using a dog, Ivan Pavlov demonstrated that through conditioning, a stimulus other than the original can elicit the same response from an animal as the original.



ducting these experiments were very influential in the development of the methodology of the psychology of learning. He is also credited with introducing aseptic surgery and the objective, repeated experiment into physiology.

Pavlov was born at Ryazan. He originally intended to become a priest but left the theological seminary in 1870 to study natural science at the University of St. Petersburg. After receiving his medical degree in 1883, he spent two years of further study in Germany. He was director of physiology at the St. Petersburg Institute for Experimental Medicine for five years and also held the chair in physiology at the Military Medical Academy. It was at the academy that he carried out most of his experiments until the Soviet government provided him with a laboratory of his own at Koltushig.

He was a vociferous critic of the Communist government until his death, but the government tolerated his criticism because of his position in the scientific community. His theories are still popular in the Soviet Union today, though they have diminished in authority elsewhere. His published works include *The Work of the Digestive Glands* (translated 1902), *Conditioned Reflexes* (translated 1927), and *Conditioned Reflexes and Psychiatry* (translated 1941).

PEARY, ROBERT EDWIN (1856–1920)

The U.S. explorer Robert Peary was the first man to reach the North Pole. He faced great hardship in his struggle to do so, and his endurance was tested again and again.

Peary was born in Cresson, Pennsylvania. After graduating from Bowdoin College, Brunswick, Maine, he joined the U.S. Navy as a civil engineer and participated in an engineering survey for a proposed canal through Nicaragua. The project, however, never came to fruition.

His first trip to Greenland was made in 1886, when he set out from Disko Bay and sledged over the Greenland ice sheet for 100 miles, further than anyone had gone before. In 1891 he returned with seven companions. After spending the winter in Hvalsund, making friends with the Eskimos, they sledged 1,200 miles to the northeast of Greenland. On this second trip Peary discovered Independence Fjord and determined the insularity of Greenland.

He made further expeditions in 1894, 1896, and 1897, but his progress was halted by the heavy concentration of ice. In 1898 he formally announced his drive to find the North Pole, and the Peary Arctic Club of New York was formed to give support to his ventures.

He spent four years looking for routes and testing his ideas about survival. Convinced that Arctic explorers must live like Eskimos, he experimented with living in igloos and with fishing and hunting for food.

During this period the ship *Roosevelt* was built to Peary's specifications. It utilized 1,000-horsepower steam engines, and its wooden hull was made especially strong to enable the ship to crash through the icy barriers. Previously, explorers had relied on sails, with engines as simply a secondary source of power.

Robert Peary

In 1905 the *Roosevelt* carried Peary's party to Ellesmere Island. He returned to Ellesmere Island in 1908, and in March 1909 he left Cape Columbia on his successful journey to the pole. Twenty-seven people started on the expedition, but the sledging was arduous and many dropped out along the way. When Peary finally reached the pole, he was accompanied by a Negro aide, Matthew Henson, and four Eskimos.

Arriving home, Peary found to his dismay that Frederick Albert Cook claimed to have reached the North Pole in 1908, before Peary. Most scientists, however, credit Peary with discovering the North Pole.

The northernmost section of Greenland was named Peary Land in his honor. In 1911, in recognition of his achievement, he was named a rear admiral in the U.S. Navy.

PERRIN, JEAN BAPTISTE (1870–1942)

The French physicist Jean Baptiste Perrin first became known for his study of cathode rays. More important, however, was his calculation of Avogadro's number through study of Brownian movement, work for which he was awarded the 1926 Nobel Prize in physics.

In 1895 Perrin proved that cathode rays consist of charged particles and are not a form of wave motion. The fact that cathode rays can penetrate sheets of glass and other materials had given rise to the theory that they were waves. Perrin collected cathode radiation in a metal cylinder, which became negatively charged. By bombarding a negatively charged fluorescent screen with the rays, he also demonstrated that a negative electrical charge repelled them. These experiments showed conclusively that cathode radiation consists of negatively charged particles.

Perrin's work prepared the way for J. J. Thompson's experiments in 1887. Thompson determined the mass of cathode-ray particles, demonstrating that they are much smaller than atoms.

At the beginning of the twentieth century, Dalton's atomic theory was not yet completely accepted. Friedrich W. Ost-

With a microscope, Jean Baptiste Perrin counted the particles in a drop of water, which led to his determination of Avogadro's number and demonstrated the existence of atoms.

wald was the chief opponent of those who accepted the hypothesis that matter is composed of atoms. In an attempt to prove the atomic theory, Perrin studied Brownian movement. Through a microscope he counted the number of small particles suspended in a drop of water. He found that the density of particles at different heights in the solution could be predicted by equations worked out by Einstein in 1905. Noting the rate of diffusion of particles in the solution, Perrin was able to calculate the approximate size of atoms and molecules by actual observation. The results of this experiment enabled him to determine Avogadro's number, the number of molecules in a gram molecule of any substance. It was for this work, which convinced the scientific world of the existence of atoms, that Perrin received the Nobel Prize.

Jean Baptiste Perrin

Perrin was born at Lille, France, and earned his doctorate at the École Normale Supérieure in Paris. He was professor of physical chemistry at the University of Paris until his anti-Fascist activities forced him to flee to the United States in 1941. Thereafter he continued to support the liberation movement from New York until he died.

His work on cathode rays was published in *Comptes Rendus* in 1895, and his papers on Brownian movement appeared in 1909. His book *Les Atomes,* originally published in 1913, is considered a classic of scientific literature.

PERUTZ, MAX FERDINAND (1914–)

For developing techniques that made feasible the structural analysis of proteins, Max Perutz, Austrian-born British chemist and crystallographer, shared the 1962 Nobel Prize in chemistry with John C. Kendrew, a colleague at Cambridge University. Perutz is known best for his work on the structure of hemoglobin and for opening the way to solving the structure of crystalline proteins by x-ray analysis. (*See* John Cowdery Kendrew.)

Perutz was born in Vienna and attended the University of Vienna from 1932 to 1936. The following year he went to England and began his research on hemoglobin at the Cavendish Laboratory of Cambridge University, where he obtained his doctorate in 1940. At Cambridge, in 1947, Perutz and Kendrew founded the Medical Research Council Unit (later, Laboratory) for Molecular Biology. This was the site of such breakthroughs as solving the structure of DNA (dioxyribonucleic acid) and the discovery of the nature of the genetic code.

In 1937 Perutz and others took the first x-ray diffraction pictures of crystals of hemoglobin and chymotrypsin. It was known then that all chemical reactions in living cells are catalyzed by enzymes, and it was suspected that all enzymes are proteins; but without a knowledge of their structure, their catalytic function could not be understood. To solve their structure, it was necessary to determine the sequence of amino acid residues along the polypeptide chain and to study their three-dimensional nature. X-ray crystallography proved to be the most effective method for the latter problem, to which Perutz devoted most of his time between 1937 and 1953. In the latter year he added a single atom of a heavy metal, such as mercury or gold, to each molecule of protein and found the diffraction picture to be considerably altered. (The heavier an atom is, the more efficiently it diffracts x-rays.)

Applying Perutz' method to the muscle protein myoglobin, Kendrew and his associates obtained the first three-dimensional picture of that protein in 1957. Perutz and his colleagues obtained a three-dimensional picture of hemoglobin two years later.

In 1962 Perutz and Hilary Muirhead demonstrated that the reaction with oxygen in hemoglobin is accompanied by a change in the structure of the molecule. This discovery had wide applications in the study of other enzymatic changes.

Meanwhile, as a sideline Perutz was interested in the flow of glaciers. In 1938 he worked on a crystallographic study of the transformation of snow into glacier ice, and in 1948 he and his colleagues proved that glaciers flow fastest at the surface and slowest near the bed.

PETRIE, SIR WILLIAM MATTHEW FLINDERS (1853–1942)

For more than fifty years Sir Flinders Petrie conducted large archaeological expeditions in Egypt and Jerusalem. He is recognized for his discoveries and his development of new methods of excavating.

Petrie was born at Charlton, near Greenwich, England. A frail child, he did not attend regular school and was educated privately. From 1892 to 1933 he was professor of Egyptology at University College, London.

The first of his many expeditions to Egypt took place in 1880; and over the years he excavated many temples, pyramids, and ancient cities and towns. Among his major discoveries were the painted pavement at Tell el Amarna, the temples at Thebes, the great burying ground at Abydos, and the Twelfth Dynasty jewels at Al Fayyum.

Petrie was knighted in 1923. He published more than forty works and many plates. His autobiography, *Seventy Years in Archaeology,* appeared in 1931.

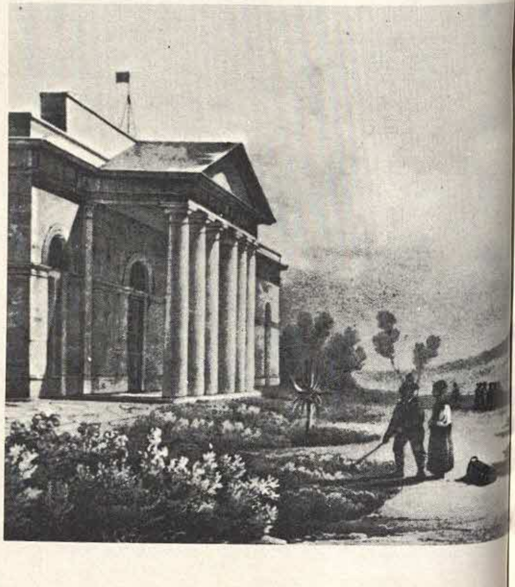
PIAZZI, GIUSEPPE (1746–1826)

The Italian astronomer Giuseppe Piazzi discovered the first minor planet, Ceres, and established that the proper motion of stars was a much more common phenomenon than had previously been thought. While professor of mathematics at the University of Palermo in 1780, he was instrumental in having the rulers of the kingdom of Naples establish observatories at Naples and Palermo.

To prepare himself for the directorship of these establishments, Piazzi spent three years as an apprentice at the observatories of Paris and Greenwich. While in England he met William Herschel, the English astronomer; and it is said that he fell off the ladder of Herschel's great reflecting telescope and broke his arm.

On his return to Palermo, Piazzi

At the instigation of the Italian astronomer Giuseppe Piazzi, the Bourbon rulers of Naples established an observatory there.



Giuseppe Piazzi

mapped with great accuracy the positions of 7,646 stars; the resulting catalog made him internationally famous. These observations, made between 1792 and 1813, proved that the proper motions first observed by Halley are common to almost all stars. He also discovered the dim star 61 Cygni, which he showed to have a very rapid proper motion.

In 1801, while making his systematic observations of the stars, Piazzi noticed one that apparently changed its position over a period of several days. Following its course, he deduced that it must lie between Mars and Jupiter: its velocity was less than that of Mars and greater than that of Jupiter. Before he could determine the orbit of this body, which he thought was a planet, he became ill; and it was subsequently rediscovered by Baron von Zach. Piazzi, however, is credited with the discovery, since he was the first to sight it. It was found to be a planetoid, or minor planet, and was named Ceres; its diameter is known today to be 485 miles.

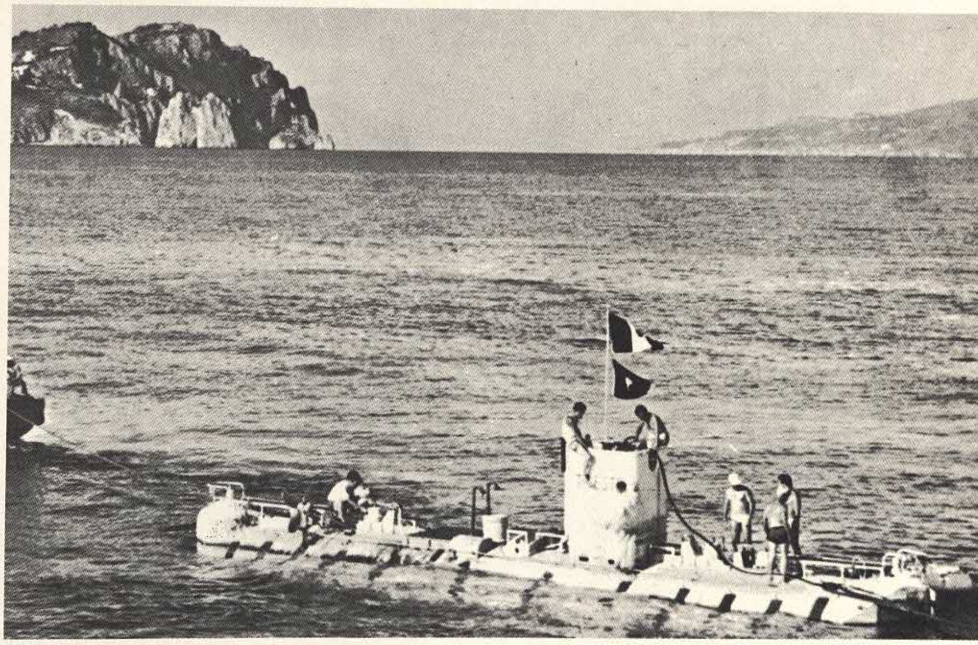
Piazzi's discovery led other astronomers to search for additional objects in the same area of the sky where Ceres was found; three other planetoids were discovered during Piazzi's lifetime. Today more than 1,600 minor planets are known. The thousandth planetoid to be discovered was named Piazzia in his honor.

Piazzi, born in Ponte in the Valtellina, was a monk and priest of the Theatine order. His early education was in philosophy, and only later in life did he turn to the study of mathematics and astronomy.

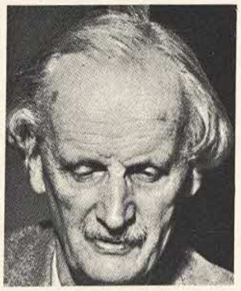
PICCARD, AUGUSTE (1884–1962)

The Swiss physicist Auguste Piccard became well known as an explorer of the stratosphere and the deepest parts of the world's oceans. His interest as a physicist in cosmic rays and the ion-filled layers of the stratosphere led to his early attempts to penetrate the upper reaches of the atmosphere.

In 1913 Piccard, with his twin brother Jean, made a sixteen-hour balloon ascent from Zürich; and in 1931 and 1932 he used an airtight aluminum gondola suspended from an hydrogen balloon, which he had developed himself, to ascend to record heights of 51,961 feet (Augsburg, May 1931) and 53,139 feet (Zürich, August 1932). On these ascents he collected information on cosmic rays, radioactivity, and electricity in the upper atmosphere. The Augsburg ascent was the first penetration of the stratosphere by man and was twice as high as anyone had ever risen before. Piccard made twenty-seven ascensions before turning his energies to other work.



In January 1960 Auguste Piccard's bathyscaphe the *Trieste* descended 35,800 feet below sea level to the bottom of the Marianas Trench.



Auguste Piccard

In the late 1930s his interests turned to the oceans; and in 1946, after a delay caused by World War II, construction began on his bathyscaphe, a navigable submersible ship consisting of an airtight steel sphere suspended from a heptane-filled float. It could descend to great depths, and the sphere served as an observation cabin from which the divers could examine the ocean bottom. Unlike former devices, the bathyscaphe was not connected by cables to a surface ship; it descended by filling its tanks with water and ascended by jettisoning ballast. In his second bathyscaphe, the *Trieste*, Piccard, together with his son Jacques, descended to a record depth of 10,335 feet off Capri in 1953. A depth of 13,287 feet was reached off the Mediterranean coast of Africa in 1954 by two French naval officers in this ship. In 1960, two years after being acquired by the U.S. Navy, the *Trieste* descended 35,800 feet below sea level to the bottom of what is thought to be the deepest spot in the oceans, the Marianas Trench, off Guam in the Pacific Ocean.

Piccard was born at Basel, Switzerland, and educated there and at Zürich. He taught at the latter place from 1907 to 1922, after which he was professor of physics at the Polytechnic Institute in Brussels, Belgium. In 1956 he published *In Balloon and Bathyscaphe,* an account of his explorations.

PLANCK, MAX KARL ERNST LUDWIG (1858–1947)

The greatest single influence on all branches of modern physical science was the quantum theory introduced by the German physicist Max Planck. For this outstanding contribution, he was awarded the 1918 Nobel Prize in physics.

Planck was the first man to grasp one of the most important characteristics of the physical universe, the discontinuity of energy, which was to be confirmed in subsequent years by studies on atoms and their nuclei. Energy, before Planck's time, was thought of as an entity that could take any value whatsoever; that is, a continuous phenomenon. Planck's work on blackbody radiation, however, led him to the conclusion that energy exists in finite, discrete packets; that is, it cannot take any arbitrary value and is discontinuous. Each of these packets is known as a quantum. The concept of quanta has since influenced virtually all of modern physical science.

Max Planck, celebrated for his quantum theory, with its far-reaching effects on the physical sciences, received his first scientific inspiration at the Maximilian Gymnasium in Munich.

Planck was born at Kiel, Germany, to a family of theologians and jurists. When he was nine, his family moved to Munich, where his father had been appointed professor of law. His youthful interests were divided between art and science. At school he was brilliant at mathematics, but his ruling passion was music. While a student at the University of Munich, he was leader of the orchestra and choirs of a private musical society, played the organ for the religious ceremonies at the university, and composed music. He even succeeded in putting together a chamber operetta. Eventually, he dedicated himself to science, which he had studied at the university, but music always remained a great solace to him.

After three years at Munich he spent a year in Berlin studying physics with Hermann von Helmholtz and Gustav Kirchhoff and made a special study of the works of Rudolf Clausius, a founder of thermodynamics. Planck obtained his doctorate from the University of Munich in 1879 and lectured there until 1885, when he was appointed professor of theoretical physics at the University of Kiel. In 1889 he accepted a full professorship at the University of Berlin, where he taught for forty years and was also chancellor from 1913 to 1914. He retired from teaching in 1928 but continued to write and study. He was president of the Kaiser Wilhelm Institute, a member of the Academy of Sciences, and a recipient of the Rockefeller Prize and the Planck Medal.

The numerous honors that he received, however, could not compensate for the many losses that he suffered in his private life. From two marriages he had five children, but two of his sons died tragic deaths: one was killed at Verdun during World War I, and the other was killed by Gestapo agents in 1945 after he had taken part in an attempt on Adolf Hitler's life. Planck was one of the few Germans who dared to protest the racial policies of Hitler, and as a result he was reduced to silence and oblivion. After the destruction of his house in Berlin and the dispersal of his library during World War II, Planck retired to Göttingen, where he spent the last two years of his life, honored and respected.

PLATO (427?–?347 B.C.)

The Greek philosopher Plato, whose original name was Aristocles ("Platon" was a nickname referring to his broad shoulders), was born in Athens to aristocratic parents. He was a pupil of Socrates and the teacher of Aristotle. Plato was not a scientist but a metaphysician; nonetheless, his influence on the history of science is considered to be immense.

By the time of Plato, Greek science was already well advanced. The Milesians, with a scientific tradition going back to Thales, had attempted to explain natural phenomena, including human behavior, without recourse to supernatural causation. This was a major step forward in science. Rudimentary experimental and observational techniques were developing, which prompted open debate among learned men on the validity of data derived from sense-experience. Mathematics, especially geometry, was considered important enough to be studied widely.

Plato's thought, through his dialogues (which are extant) and his lectures at his Academy (which are lost), exerted a profound influence on these trends, both negatively and positively. The emphasis on the supernatural in Plato's cosmology is thought to have retarded the growth of objective astronomy; but at the same time this emphasis made astronomy more respectable and acceptable to more students, since many were opposed to what they considered to be an atheistic approach. Plato was also hostile to systematic experimentation and discouraged observation. It is thought that he thereby retarded the growth of observational methodology in many budding sciences. For political reasons he refused technology a high place in his system of society, and it is possible that this influence retarded technical advance. Plato's high regard for pure mathematics, however, contributed, although indirectly, in a positive way to the growth of that science. His reputation led students to mathematical studies in his own time and in the Middle Ages as well as at present. His direct contribution to mathematics was in the realm of pure theory; he despised applications. Under the influence of the Pythagoreans, he derived the five (and only five) regular polyhedrons, which have equal sides and equal angles, the so-called Platonic bodies. Kepler developed the first unitary scheme of the universe (A.D. 1596) through the study of this phenomenon.

Plato denied that knowledge could be gained by interrogating nature; yet this is the basis of modern scientific method, without which scientific advance would have been impossible. Although it can be said that Plato did much to discourage the development of science, his contributions to the philosophy of science were great; and his Academy organized human thought and effort at Athens until it was closed by Emperor Justinian in A.D. 529. Plato's views influenced the method of science for many centuries; whereas the views of Aristotle, who held scientific observation in high regard and practiced it himself, did not gain dominance until the thirteenth century.

POINCARÉ, HENRI (1854–1912)

The French mathematician Henri Poincaré made significant contributions to almost every area of applied mathematics. In addition to concerning himself with mathematical theory, he also did important work in the fields of physics and astronomy.

Poincaré—a cousin of Raymond Poincaré, the French president during World War I—was born at Nancy, France, and educated at the École Polytechnique and the École des Mines. After graduating as a qualified mining engineer in 1879, he became a lecturer at Caen University. Two years later he began his long association with the University of Paris: in 1881 he became professor of physical mechanics; in 1886, professor of mathematical physics and the calculus of probabilities; and, finally, professor of celestial mechanics.

In the area of pure mathematics Poincaré generalized the idea of functional periodicity in his theory of automorphic functions and introduced Fuchsian functions. He also applied non-Euclidean geometry to the theory of quadratic forms and did important work on integral curves, differential equations, and the theory of probability.

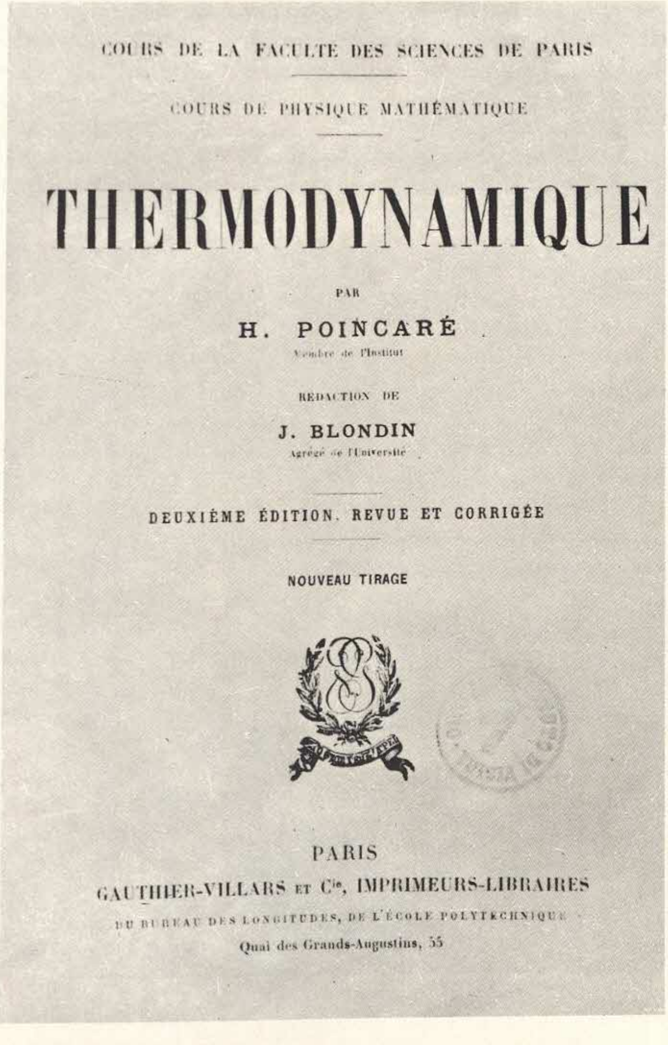
Poincaré reconstituted analytical mathematics and applied analysis to rational mechanics, physics, and astronomy. In his work on celestial mechanics he added to the theory of orbits in regard to the problem of three bodies. While working on the theory of periodic orbits, he founded the study of topological dynamics, which is considered to mark the beginning of modern topology.

His contributions to physics were in his studies of the electromagnetic theory of light, electric oscillations, and the diffraction of hertzian waves. In his work on the dynamics of the electron, the results of which were published in 1906, he independently arrived at some of the same conclusions as Einstein regarding the special theory of relativity. Poincaré stated that all velocities are relative and that nothing can exceed the speed of light.

In recognition of his accomplishments he was made a member of the Academy of Sciences in 1887 and the French Academy in 1909. He was elected a foreign member of the Royal Society in 1894. During his lifetime he wrote more than 30 books, including several on the philosophy of science, and about 500 lesser works.

Although Henri Poincaré was primarily a mathematician, he was active in most scientific fields and was the author of many works on pertinent subjects, as well as a number of more general publications that propounded a relativistic philosophy.

Henri Poincaré



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Quai des Grands-Augustins, 55

POPOV, ALEKSANDR STEPANOVICH (1859–1906)

The Russian physicist and electrical engineer Aleksandr Popov was one of the first men to investigate electromagnetic waves as they were used later in wireless communication. An outstanding scientific contribution was the development of an apparatus for detecting lightning discharges at a distance.

Popov was born in a Ural Mountain village and received his education at the University of St. Petersburg. After graduating in 1883, he became an assistant in a physics laboratory and then joined the staff of a school at Kronstadt, where he later headed the physics department and began work on his device to detect lightning discharges. This apparatus later was connected to a lightning conductor and became a successful instrument to study atmospheric electric discharges.

In 1896 Popov was inspired by the news of Marconi's new wireless telegraph and by 1898 was able to establish ship-to-shore communication with a Russian naval vessel. The Russian government was not impressed, however, and in 1901 he returned to St. Petersburg as professor at the electrotechnical institute, later becoming its director.

PORTER, GEORGE (1920–   )

While director of the Royal Institute of Great Britain, the British chemist George Porter shared half of the 1967 Nobel Prize in chemistry with his former teacher the British chemist Ronald Norrish. The other half of the prize was given to the German chemist Manfred Eigen. The three were cited for their studies of extremely fast chemical reactions. (*See* Manfred Eigen; Ronald George Wreyforth Norrish.)

Porter was born at Stainforth, Yorkshire. After undergraduate work at Leeds, where he took his bachelor's degree in 1941, he served as a naval radar officer during World War II and then received his doctorate from Cambridge University in 1949. He remained there and from 1949 to 1955 conducted the prizewinning work with Norrish. In 1955 Porter became professor of chemistry at the University of Sheffield, where he continued his research independently, becoming Firth Professor of Chemistry in 1963. He was also professor of chemistry at the Royal Institute in London from 1963 until 1966, when he was named its director and Fullerian Professor of Chemistry.

George Porter

He was elected a fellow of the Royal Society and of the Royal Institute of Chemistry, an officer of the Faraday Society, and an honorary teacher at the University of Kent. In addition, he served as assistant director of the British Rayon Research Association and as Remsen Memorial Lecturer for the American Chemical Society. His *Chemistry for the Modern World* was published in 1962.

POWELL, CECIL FRANK (1903–)

The work of the British physicist Cecil Powell made it possible to use the photographic method in nuclear research. He also discovered the production of a new particle, the pi-meson, from cosmic radiation in the Earth's atmosphere. For these achievements, he was awarded the 1950 Nobel Prize in physics.

Powell was born at Tonbridge, Kent, England. After receiving his doctorate from Cambridge University in 1927, he joined the staff of the University of Bristol as a researcher and was appointed professor of physics there in 1948.

Powell early became interested in the use of photographic emulsions to record certain charged particles. As the particles passed through the emulsion, they picked up grains of silver iodide; and when the photographic plate was developed, these grains appeared as a line of dark specks. The faster the particles moved, the wider apart the dark grains. The distance between the grains could be used to measure the speed of the particles. The Wilson cloud chamber technique was the method that had been used previously to investigate such particles, but it had limitations.

During World War II, Powell and his colleagues at Bristol University worked to improve photographic emulsions. Their research resulted in the development of the Ilford halftone emulsion, which Powell used in 1947 to investigate cosmic-ray showers. He exposed some of these emulsions in the Pyrenees Mountains at 9,000 feet above sea level. An analysis of the plates later revealed a new particle, one that varied from one discovered earlier by Carl David Anderson, whose particle, called a meson, was considered proof of the theories of Hideki Yukawa. The new meson discovered by Powell was heavier than Anderson's and was named a pi-meson, or pion, while Anderson's was named a mu-meson, or muon. Powell continued experimenting with photographic emulsions and launched balloons and rockets to investigate cosmic-ray activity at heights of more than 100,000 feet.

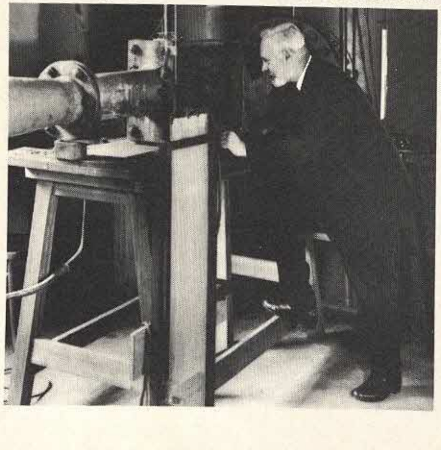
In 1949 he was elected a fellow of the Royal Society and that same year won its Hughes Medal and in 1961 its Royal Medal. He coauthored *Nuclear Physics in Photographs* (1947) and *Study of Elementary Particles by the Photographic Method* (1959).

PRANDTL, LUDWIG (1875–1953)

The German physicist Ludwig Prandtl is considered a pioneer in the field of aeronautics. His work led to many advances in the designs of ships and airplanes.

Prandtl was born at Freising, Bavaria. He qualified at Munich in 1900 with a thesis on elastic stability and in 1904 became professor of applied mechanics at the University of Göttingen, where he remained the rest of his life. In 1925 he was named director of the Kaiser Wilhelm Institute for Fluid Mechanics.

His experiments on friction drag made Ludwig Prandtl a pioneer in the field of aeronautics.



Prandtl's first major discovery was of the "boundary layer" adjoining the surface of a body moving in air or water. This led to an understanding of friction drag and the way that streamlining reduces the drag of such bodies. He also developed theories about turbulence and supersonic flow, and his research is considered basic to aerodynamics.

PREGL, FRITZ (1869–1930)

By developing the elementary techniques of quantitative organic microanalysis, the Austrian chemist Fritz Pregl became the founder of organic microchemistry. For this work he was awarded the 1928 Nobel Prize in chemistry.

Pregl was born at Laibach, Slovenia (now Ljubljana, Yugoslavia). After receiving his medical degree from the University of Graz in 1894, he taught for a time at the Physiological Institute at Graz and then studied chemistry at the universities of Leipzig and Berlin. In 1904 he became professor of physiological chemistry at the Medico-Chemical Institute at Graz; from 1910 to 1913 he was professor of applied chemistry and head of the chemical department of the medical school at the University of Innsbruck; and in 1913 he returned to Graz as director of the Medico-Chemical Institute.

For a while Pregl practiced medicine, specializing in eye surgery. He was more interested in pure research, however, and began experimenting with the physiological chemistry of bile acids. Since these acids could be obtained only in small amounts, he became interested in finding a method for analyzing quantities too small to be studied by ordinary chemical means. He set up delicate measuring instruments and by himself created most of the special apparatus needed for dealing with miniscule amounts of substances. This marked the beginning of organic microchemistry. By 1913 Pregl was able to apply his methods of microanalysis to amounts weighing as little as three milligrams. Soon after the results of his work had been published in 1917, his microanalytical techniques were adopted by organic chemists all over the world. He also devised a test for finding the functional capacities of kidneys and made up a mild iodine solution for use as an antiseptic.

In 1914 he was awarded the Lieben Prize of the Vienna Academy. An honorary doctorate was conferred upon him by the University of Göttingen in 1920.

PRIESTLEY, JOSEPH (1733–1804)

The great achievement of the dissenting English minister and amateur chemist Joseph Priestley was the discovery of oxygen, though he also discovered several other gases and invented systems for collecting them. Today his critics lament the fact that he did not exploit his fantastic discoveries to demolish the theory of phlogiston, the mysterious element that was used to explain the phenomena of combustion and various reactions among gases. Priestley, however, unquestioningly accepted the phlogiston theory and did not thoroughly penetrate the significance of his own discoveries.

Priestley, who was born at Fieldhead, near Leeds, England, lost his mother when he was seven and was reared by an aunt of strong character and open mind who liked to entertain freethinkers in her home. She gave the boy a rather unconventional education, quite different from the teaching he had received from his Calvinist parents. Priestley was a diligent student but not an exceptional one; however, he had a talent for languages and learned French, German, Italian, Greek, Latin, and the rudiments of oriental ones on his own. He entered the Theological College at Daventry after the local college had refused him admission because of his daring opinions on original sin and eternal damnation. After taking orders, he became a minister at Needham, then at Nantwich, and finally at Warrington, where he was invited to teach languages and literature at the college. While teaching at Warrington, he earned a doctorate of laws degree from the nearby University of Edinburgh.

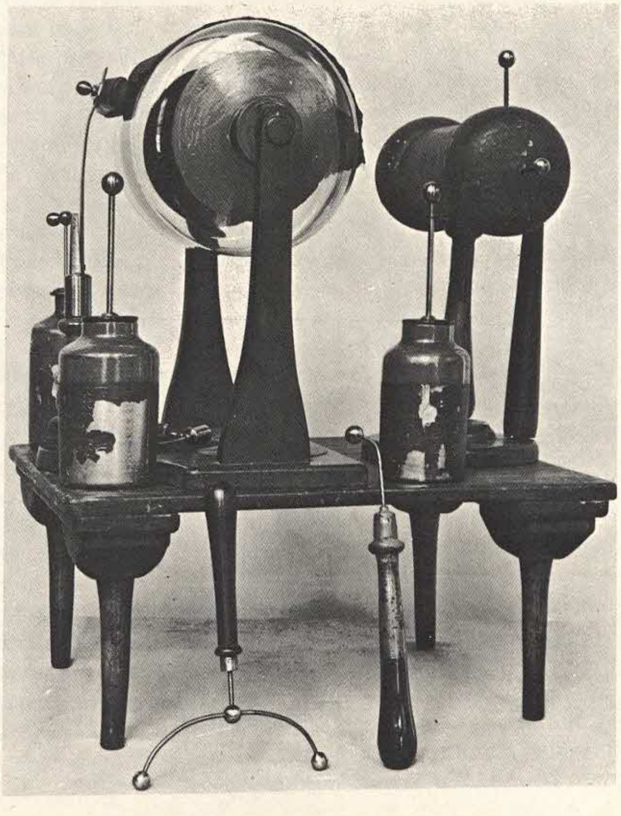
During a visit to London he met Benjamin Franklin, who had come to plead the cause of the American colonies. Franklin initiated him to the study of electricity, which fascinated Priestley so much that two years later he wrote his brilliant *History and Present State of Electricity*, thereby gaining admission to the Royal Society.

In 1767 he moved to Leeds, where a chance event introduced him to a new science, that of gases. While on a visit to a brewery, he was attracted by the gas that fermentation produced in large quantities and decided to experiment with it. Before long he discovered that this strange gas (now known as carbon dioxide) could be produced by pouring acid on chalk and that it had the property of dissolving in water. Having realized that it was an innocuous gas, he tried drinking the water and found it pleasant tasting. This is how soda water first came about. The discovery of the solubility of carbon dioxide in water was so important that Priestley was awarded the Copley Medal by the Royal Society in 1773.

At that time, to collect an artificially produced gas, it was necessary for the gas to bubble in a water-filled cylinder inverted over a container of water. As the gas gradually expanded, it rose in the cylinder, displacing the water. Priestley noticed that in certain cases, however, the gases, instead of collecting, dissolved in the water, and realized that if he wished to pursue his studies on the properties of pure gases, he would have to modify the system of collecting them. He achieved success by replacing the water with mercury.

A chance meeting with Benjamin Franklin in 1765 was instrumental in Joseph Priestley's decision to pursue a scientific career. Inspired by Franklin, he became interested in electricity and even constructed an electrical cylinder machine.

Joseph Priestley



Continuing with his research, he managed to produce a new gas by heating red mercuric oxide. Filled with his usual curiosity, he experimented to find the properties of this new gas and their effect on flames. Whereas some gases stifled them, this one kindled them: embers glowed brightly in it, and a candle grew brighter and burned more quickly. On making various animals breathe it, he found that they remained alive. This was the discovery of oxygen. Priestley, however, thought that he was dealing with something like dephlogisticated air. Nonetheless, he had clearly discerned the element's function in respiration. With great courage he tried breathing the new gas himself and felt a pleasurable sensation: breathing was easier, and he had a feeling of well-being. In 1774, while traveling in Europe, Priestley met Antoine Lavoisier in Paris. He communicated his recent experiments on oxygen to the French scientist, who used them in destroying the phlogiston theory. Priestley also discovered nitrogen, ammonia, nitrogen dioxide, nitrous oxide, hydrogen chloride, and sulfur dioxide.

Priestley always championed the cause of liberty. Siding openly with the American colonies, the French revolutionaries, and those who favored the separation of church and state, he thereby attracted the hostility of conservatives. On the evening of July 14, 1791, a mob instigated by the agents of King George III attacked and ravaged Priestley's house. He took refuge in London; but two years later, realizing that he would never be left in peace in his native country, he went to the United States and settled in Northumberland, Pennsylvania, where he resumed his experiments.

PROKHOROV, ALEKSANDR MIKHAYLOVICH (1916–)

The Soviet physicist Aleksandr Prokhorov shared the 1964 Nobel Prize in physics with his fellow Soviet scientist Nikolai Basov and the U.S. physicist Charles Townes. All three were honored for their fundamental research on the maser-laser principle. Basov and Prokhorov discovered the maser principle in 1953, and Townes is generally credited with inventing the first maser. (*See* Nikolai Gennadievich Basov; Charles Hard Townes.)

Maser stands for *m*icrowave *a*mplification by *s*timulated *e*mission of *r*adiation. The laser substitutes light for microwaves. Basov and Prokhorov had to find a new method for amplifying electromagnetic radiation. They succeeded in creating secondary waves at a sufficient rate of speed and knew that the next stop was to upset the equilibrium of the electrons forming the waves, while maintaining the energy levels. Townes later succeeded in doing this.

The efforts of the three men created the field of quantum electronics, which applies quantum mechanics to electronics: matter and radiation are made to interact within measurable terms. Lasers and masers are practical offshoots of this branch of study. Prokhorov worked on the maser-laser principle beginning in 1950.

He was born in Atherton, Queensland, Australia, where his family had immigrated from Russia for political reasons. After the Bolshevik Revolution in 1917, the family returned to Russia; and in 1939 Prokhorov was graduated from Leningrad University. In 1946, after serving in the army during World War II and being wounded, he became senior associate at the P. N. Lebedev Institute of Physics in Moscow, a research arm of the U.S.S.R. Academy of Sciences, and remained in that position until 1954, when he was appointed head of its oscillation laboratory. Meanwhile, in 1951, he had received a doctorate in physical-mathematical sciences from the institute. He also taught at Moscow State University.

In 1959 Basov and Prokhorov received the Lenin Prize for their discovery of the maser principle. The following year Prokhorov was elected a corresponding member of the U.S.S.R. Academy of Sciences.

PTOLEMY (second century A.D.)

Much of the work of the Greek astronomer, geographer, and mathematician Ptolemy is noted mainly for its historical value. For more than 1,200 years his influence was equaled only by that of Aristotle. Ptolemy not only studied all the works of astronomy available at the time but also summarized them all in a single work, the *Almagest*, which was the only astronomical encyclopedia of undisputed validity until the time of Copernicus. Ptolemy also built instruments for observing the sky, which enabled him to make many important discoveries; dedicated himself to geometry; applied trigonometry to astronomy, thereby giving astronomy a strictly mathematical form; and made maps.

Despite his enormous fame throughout the entire ancient world, almost nothing is known of Ptolemy's life. Both the date and the place of his birth are uncertain. His supposed birthplace was Ptolemais Hermii, a Greek colony in Egypt, where it is thought that he was born to Greek parents. As for his birth date, the only thing that can be determined, using his astronomical observations as a guide, is that he worked in Alexandria between 127 and 151.

Ptolemy's astronomical work began with a catalog of 1,022 stars. Hipparchus had been one of the first scientists to think of cataloging the stars and drawing up celestial maps to see whether there was any change in the position of the stars; and his work served as a basis for Ptolemy, who was able to make substantial amendments toward perfecting celestial cartography. The truest observations of ancient times were those carried out by Ptolemy, which provided a record of the variations in the light of the stars down through the centuries.

Among the astronomical instruments devised by Ptolemy were the armillary sphere for calculation of the celestial coordinates, the mural quadrant for measuring the distance to the sun, and the rules for measuring the positions of other celestial bodies. By means of the observations carried out with his instruments, Ptolemy was able to compile fairly accurate tables of the motions of heavenly bodies, which made it possible to set down exact calculations for interpreting their movement.

Having invented the instruments for studying the stars and planets and having measured their movements with some precision, Ptolemy arrived at the theory of the movement of heavenly bodies. From this followed the geocentric theory, which had already been formulated by Hipparchus. It was expanded by Ptolemy, and until the fifteenth century it was universally believed to be valid.

By a system that was complex but geometrically without objection, Ptolemy attempted to explain the peculiarities in the motion of planets known as stations and retrograde motion. At certain points in their orbits the planets seemed to stand still, invert their motion, stop again, and then continue their motion in the original direction. It is now known that this occurs because the Earth and the planets move at different velocities in more or less circular, concentric orbits. Ptolemy, however, imagined that the Earth was at the center of a crystal sphere on which the stars were placed and that the planets were placed on smaller concentric spheres, with all the spheres moving at different velocities, which would explain the different mean velocity of the movement of each planet on the celestial vault. The retrograde motion and the stations could be explained by an epicyclic movement; that is, the planets moved on smaller spheres, or epicycles, the centers of which were situated on, and attracted by, the larger sphere.

In mathematics Ptolemy excelled as a geometrician. He introduced the theorem which now bears his name, concerning a quadrilateral inscribed in a circle; worked on the orthogonal projections of points on the celestial sphere; and drew up a table of chords. He also studied optical phenomena and invented a calendar.

The maps in Ptolemy's *Guide to Geography* were based on word-of-mouth information from travelers and for this reason were inexact. Ptolemy divided the Equator into 360° and drew up meridians and parallels, but he took the Earth's circumference to be less than it actually is. This error was reflected proportionally in the latitudes; as a result, Ptolemy's maps showed the Earth to be extremely elongated, and the lands known at that time were all placed in the Northern Hemisphere.

Understandably, he frequently arrived at mistaken conclusions, which, nevertheless, were accepted for many centuries. His belief that a continent existed in the southern part of the Indian Ocean was disproved only by Captain Cook's voyages in the 1770s. Because of Ptolemy's mistaken estimate of the extent of Eurasia, Columbus was led to underestimate the difficulty of the voyage to the East Indies and so set out, discovering America along the way.

PUPIN, MICHAEL IDVORSKY (1858–1935)

The U.S. physicist Michael Pupin invented and designed devices basic to telephone and telegraph systems. He also discovered secondary x-ray radiation; and by using a fluorescent screen, he made possible short-exposure x-ray photography.

By placing inductance coils at intervals along a transmitting wire, Pupin was able to extend the range of long-distance telephone communication, especially over cables. The Bell Telephone Company and German communications interests acquired Pupin's patent in 1901.

Pupin was born in Idvor, Hungary (now in Yugoslavia), the son of illiterate parents. Five years after arriving penniless in the United States in 1874, he enrolled at Columbia University in New York City and received his bachelor's degree in 1883. Later he studied physics and mathematics at Cambridge University in England and at the University of Berlin, where he received his doctorate in 1889. The following year he returned to Columbia as an instructor in mathematical physics, in 1892 he became a special professor of mechanics, and in 1901 he attained the rank of full professor of electromechanics. He was later appointed director of the Phoenix Research Laboratory, where he remained until his retirement in 1931. His autobiographical *From Immigrant to Inventor* was published in 1923.

PURCELL, EDWARD MILLS (1912–)

The U.S. physicist Edward Mills Purcell shared the 1952 Nobel Prize in physics with Felix Bloch for the discovery of nuclear magnetic resonance in solids, which proved useful for research in chemistry as well as in physics. Purcell, working at Harvard University, and Bloch, working across the country at Stanford University, Palo Alto, California, achieved the same results at about the same time. (See Felix Bloch.)

Together with his colleagues, Purcell discovered a way to tune in to the frequencies of atomic particles spinning in magnetic fields. This method, which involved absorption of radio-frequency waves, opened up a new field of physics—magnetic resonance spectroscopy—which yielded information on chemical bonds and atomic binding in liquids and solids and on the structure of hydrocarbons. Purcell also contributed to radio astronomy by helping detect the 21-centimeter line of neutral atomic hydrogen in extraterrestrial radiation, making possible the determination of hydrogen distribution in galaxies.

He was born in Taylorville, Illinois. After receiving his bachelor's degree in 1933 from Purdue University, Lafayette, Indiana, he spent a year at the Technische Hochschule at Karlsruhe, Germany, as an international exchange student. He earned his doctorate at Harvard in 1938. During World War II he was at the radiation laboratory of the Massachusetts Institute of Technology, Cambridge, as the leader of the Advanced Development Group on radar problems. In 1949 he was appointed professor of physics at Harvard.

Purcell was elected to membership in the American Philosophical Society, the National Academy of Sciences, and the American Academy of Arts and Sciences. In 1962 he was appointed to his second term on the President's Science Advisory Committee.

PYTHAGORAS (sixth century B.C.)

Even the most elementary students of geometry are acquainted with the famous theorem of the Greek philosopher and mathematician Pythagoras that the square of the length of the hypotenuse of a right triangle is equal to the sum of the square of the lengths of its sides. Pythagoras also contributed to the knowledge of musical intervals and made interesting observations in the field of astronomy.

The exact dates of his birth and death are not known, but it is certain that he accomplished most of his work during the mid-sixth century B.C. He was born on the Aegean island of Samos, and according to legend he traveled far and wide searching for wisdom. In about the year 530 B.C. he settled in the Greek colony of Crotona in southern Italy, where he founded the Pythagorean school of natural philosophy. Originally this cult was devoted to religion, but its interests grew to include reforms in political, moral, and social life. Since Pythagoras believed in the transmigration of souls and taught that life was a time for the purification of the soul, he and his disciples were vegetarians and advocated an ascetic mode of living. His ideas were cloaked in mysticism—a deviation from traditional Greek rationalism—and he regarded his knowledge as a great secret to be shared with only his disciples; for this reason he left no manuscripts of his work. The secretive nature of all the Pythagoreans have made it difficult to determine exactly the extent of Pythagoras' contributions to astronomy and mathematics.

In addition to presenting the Pythagorean theorem to the mathematical world, Pythagoras discovered the peculiar nature of irrational numbers, in particular the square root of the number 2: no number or fraction when multiplied by itself will result in the number 2. He and his followers believed that everything in the world could be expressed by numbers.

His greatest scientific achievement was the discovery of the relationship between

As a result of a series of experiments that revealed the relationship that exists between mathematical ratios and musical intervals, Pythagoras found that even music is ruled by mathematics. This discovery led to his concept of the harmony of the spheres.

mathematical ratios and musical intervals. He found that, given the same amount of tension, dividing the length of a musical string in half would increase the pitch of the string one octave (the shorter the string, the higher the pitch). The musical interval called a fifth was produced when the ratio of the length of the strings was three to two; a ratio of four to three produced a fourth; and the blending of certain intervals produced a chord. Somehow he conceived of the idea that the spacing of the planets was equal to a musical progression, and this led to the concept of the harmony of the spheres.

Pythagoras

In the field of astronomy Pythagoras was one of the first men to notice that the morning and evening stars are the same body (known today as the planet Venus). He was also the first proponent of the idea that the Earth and the universe are spherical in shape. He thought that each heavenly body rotated around the central fire (a force controlling the universe) in its own sphere or orbit. The concept of planetary spheres persisted for more than 2,000 years until it was discredited by Johannes Kepler.

Even though the Pythagorean school was not political in nature, it did have great influence on the politics of the day. The Pythagoreans often openly supported the aristocrats and were at odds with the democrats. As the latter gained power, the Pythagoreans were suppressed and by the middle of the fifth century B.C. were wiped out altogether. Pythagoras himself was exiled from Crotona and fled to Metapontum, where he was murdered about ten years later by an angry, politically motivated mob.

PYTHEAS (fourth century B.C.)

Pytheas

In the fourth century B.C. the Greek explorer, navigator, and geographer Pytheas sailed beyond the confines of the Mediterranean Sea and explored the coastlines of lands bordering the North Atlantic, including those of Spain and the British Isles. In the accounts of his voyages, he also mentioned attempting to reach what he called Thule, which some historians think might have been Norway.

Sailing on the open ocean, instead of the landlocked Mediterranean, he was the first Greek to observe real tides. Remarkably, he gave an accurate explanation for them, showing that their periodic fluctuations are related to the moon. His explanation, however, was not accepted until 2,000 years later, when Sir Isaac Newton explained lunar attraction. Pytheas also calculated the ratio of a sundial hand to its shadow during the summer solstice; and using observations of the sun, he managed to plot the latitude of Massilia (now Marseilles, France) with fair accuracy.

Pytheas was born at Massilia, then the westernmost Greek colony on the Mediterranean. The exact dates of his birth and death are not known, and very few of his writings are still extant.

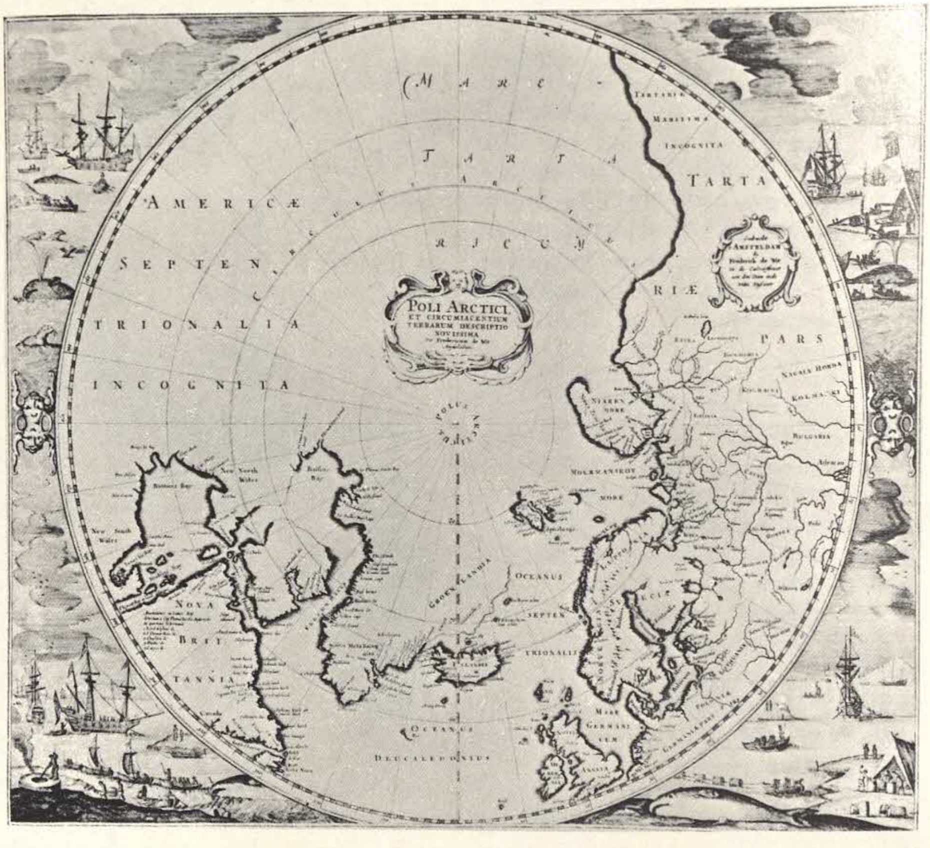
RABI, ISIDOR ISAAC (1898–)

The Austrian-U.S. physicist Isidor Rabi was awarded the 1944 Nobel Prize in physics for work that made it possible to accurately measure properties of atoms and molecules. Most of his work centered on phenomena connected with magnetic fields.

While at Columbia University, New York City, Rabi began to work with molecular beams. He applied a technique of deflection to study the hyperfine structure of atomic-energy levels. His work resulted in the development of a method that permitted the measurement of both spin and the hyperfine structure constant and, therefore, the evaluation of the nuclear magnetic moment. This method was later generalized and extended to applications in the atomic clock, nuclear magnetic resonance, and the maser and laser.

Rabi was born at Rymanow, Austria (now in Poland), and moved with his family to the United States when he was a child. In 1919 he graduated from Cornell University at Ithaca and in 1927 received his doctorate at Columbia

In accounts of his travels the Greek explorer Pytheas mentioned a land over which the sun shone brightly at midnight. It is unlikely that Pytheas ever got as far north as the polar region; but it is believed that this land, which he called Thule, might have been Norway.



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AMERICÆ SEPTENTRIONALIS INCOGNITA
TARTARIÆ PARS
POLI ARCTICI ET CIRCUMIACENTIUM TERRARUM DESCRIPTIO NOVISSIMA
OCEANUS SEPTENTRIONALIS
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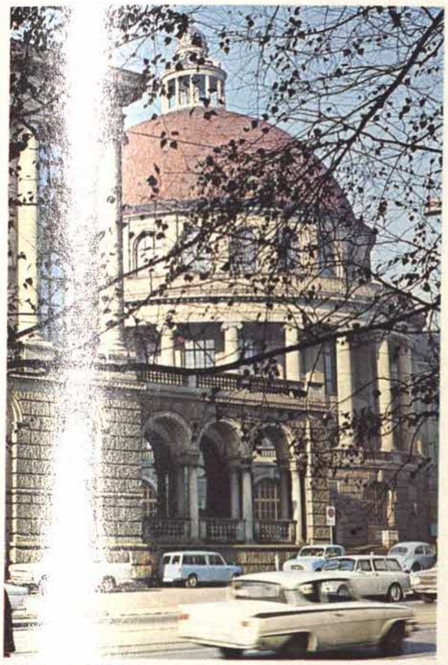
Isidor Rabi

For two years after obtaining his doctorate in 1927, Isidor Rabi studied at various prominent European institutions, among them the Federal Institute of Technology in Zürich, Switzerland.



versity. After further study in Germany, he returned to Columbia to teach and in 1937 became professor. From 1940 to 1945 he was associate director of the radiation laboratory of the Massachusetts Institute of Technology, Cambridge; and from 1946 to 1956 he was a member of the General Advisory Committee of the Atomic Energy Commission. He also served on the United Nations Science Committee and the President's Science Advisory Committee. In 1940 he was elected to the National Academy of Sciences.

RAMAN, SIR CHANDRASEKHARA VENKATA (1888–)

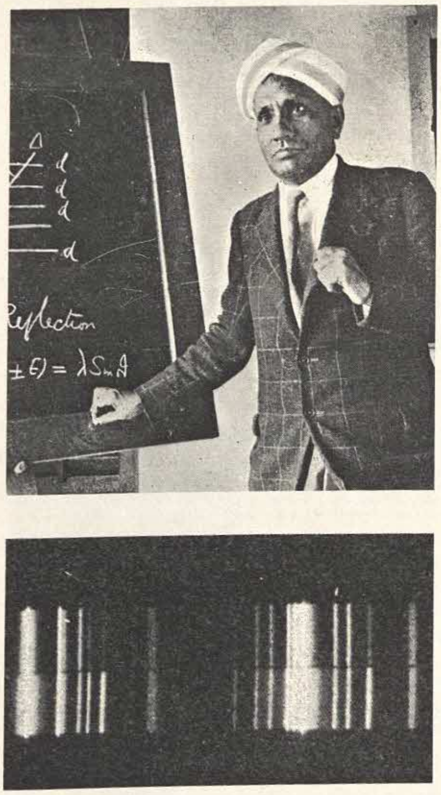
For his discovery regarding the diffusion of light, the Indian physicist Sir Chandrasekhara Venkata Raman was awarded the 1930 Nobel Prize in physics. He was the first Asian to win a Nobel Prize in any of the sciences.

His early researches were on optics, acoustics, and the theory of musical instruments. After 1921 he began studying the diffusion of light. At first he used ordinary sunlight; and later, using a spectroscope, he studied monochromatic light produced by a mercury arc lamp. In 1928 he announced the discovery that came to be known as the Raman effect, which refers to a change in the wavelength of light scattered by molecules and enables the observer to identify molecules by their characteristic frequencies. It became useful in determining the structure of molecules and also proved valuable for studying the physical states of liquids and crystals.

Raman was born in Trichinopoly, Madras, India, and educated at Presidency College and at Calcutta University, from which he received his doctorate in 1922. Since jobs in the sciences were scarce in India, Raman joined the civil service in 1907 as an accountant. In 1917 he was made a professor at Calcutta University and remained in that post until 1933, when he became head of the Department of Physics at the Indian Institute of Sciences at Bangalore. From 1914 to 1930 he was also a special lecturer in many Indian cities and in 1947 was appointed director of the Raman Research Institute at Bangalore.

In addition to carrying out original research, Raman was active in stimulating interest in the sciences throughout India. He established the *Indian Journal of Physics* in 1926 and served as general president of the Indian Science Congress in 1928. He also founded the Indian Academy of Sciences and became its president in 1934.

Among Raman's many honors was his election to the Royal Society in 1924. He was knighted in 1929 and was made a member of the Pontifical Academy of Sciences in 1961.



Sir Chandrasekhara Raman is well known for his teaching and for his work on the diffusion of light. The Raman spectra are used in qualitative and quantitative chemical analyses.

RAMON Y CAJAL, SANTIAGO
(1852–1934)

The Spanish histologist Santiago Ramon y Cajal established that the neuron, or nerve cell, is the basic unit of the nervous system. He and the Italian scientist Camillo Golgi shared the 1906 Nobel Prize in physiology or medicine for their work on the structure of the nervous system. (*See* Camillo Golgi.)

Raman y Cajal, the son of a physician, was born at Petilla de Aragon, Spain. After obtaining his medical license in 1873 from the medical school of the University of Saragossa, he served for a year as an army surgeon in Cuba, then a Spanish possession. In 1875 he was appointed assistant on the medical faculty at Saragossa, where he devoted himself to the study of anatomy. Two years later he was promoted to extraordinary professor and in 1879 became director of the medical museum of Saragossa University. In 1883 he went to the University of Valencia as professor of descriptive anatomy. He became professor of histology and pathological anatomy at the University of Barcelona in 1887. Finally, in 1892, he took the chair of histology and pathological anatomy at the University of Madrid, where he stayed until his retirement thirty years later. While holding his post at Madrid, he also served as director of the newly founded Instituto Nacional de Higiene, beginning in 1900.

About the time that Ramon y Cajal obtained his medical license, Golgi developed his silver nitrate impregnation method for staining nerve cells and their fibers black while leaving the supporting tissue, or neuroglia, stained only faintly. Earlier staining methods had revealed little differentiation between the nervous elements and their neuroglia.

In the 1880s Ramon y Cajal improved upon Golgi's staining method and began to explore the then unknown workings of the cerebrum and cerebellum. Soon he worked out the complex connections of the cells in the gray matter of the brain and spinal cord, disproving the theory that the gray matter is a network of nerve fibers and tracing long nerve fibers that never fuse with any others.

Ramon y Cajal wrote multitudinous papers and books about his research; and he also wrote an autobiography, *Recuerdos de mi vida* (1901; English translation, 1937), and *Charlas de Café* (1920), which contains anecdotes and thoughts on a variety of subjects. He was elected a foreign member of the Royal Society of London in 1909.

RAMSAY, SIR WILLIAM (1852–1916)

The British chemist Sir William Ramsay, who discovered the elements known as noble gases, was awarded the 1904 Nobel Prize in chemistry. During his early career he also made important discoveries in organic chemistry—ranging from a new bismuth mineral to the physiological action of certain alkaloids.

His collaboration with Lord Rayleigh after 1894 led to the discovery of a new gaseous, inert element that they called argon. Subsequent investigations resulted in Ramsay's isolation of neon, krypton, and xenon and, with Sir Robert Whytlaw-Gray, in his discovery of radon. Consequently, Ramsay gained the unique distinction of discovering a whole family of elements.

Ramsay was born in Glasgow, Scotland, the son of an engineer. Although he received a classical education, he was determined to make chemistry his career. He received his doctorate from the University of Tübingen in 1873 and the following year became tutorial assistant there. In 1880 he was appointed professor of chemistry at University College in Bristol and in 1887 succeeded A. W. Williamson as professor of chemistry at University College in London, where most of his research was carried out.

He was elected a fellow of the Royal Society in 1888 and was made a knight commander of the Bath in 1902. His works include *A System of Chemistry* (1891), *The Gases of the Atmosphere* (1896), *Modern Chemistry* (1901), *Introduction to the Study of Physical Chemistry* (1904), *Essays Biographical and Chemical* (1908), *Elements and Electrons* (1913), and *Life and Letters of Joseph Black* (1918).

RAY, JOHN (1627–1705)

The English naturalist John Ray is best known for his systems of natural classification of plants and animals. He was also the first to prepare a work to define species. His zoological activities have been described as the foundations of modern zoology and ornithology.

He was born at Black Notley, Essex, England, the son of a blacksmith. After receiving bachelor's and master's degrees from Cambridge, he held a succession of offices there until 1662, when he agreed to work with his friend Francis Willughby on a classification of plants and animals.

Ray's system of classifying plants was the first to distinguish the "dicotyledones" and the "monocotyledones," fundamental to modern natural classifications. He also prepared the first systematic listing of British plants. With its historical information and elaborate arrangement of the national flora, this was the most complete work ever published about plants in general. He also classified fish, animals, and insects.

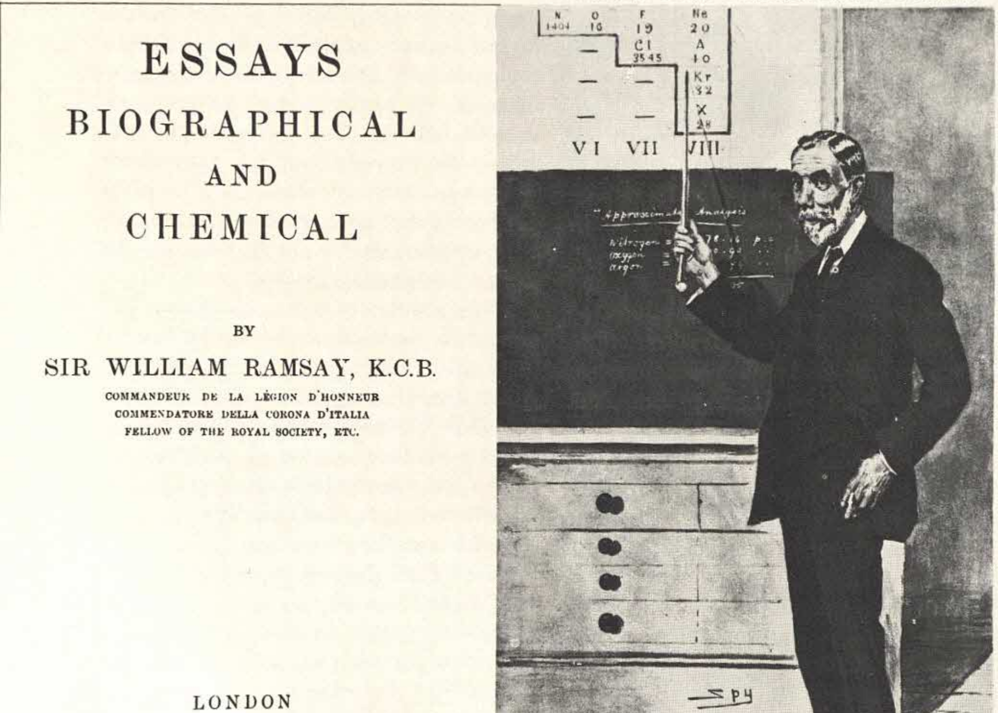
Ray was elected a member of the Royal Society of London in 1667. The Ray Society, founded in his honor in 1844, was devoted to the publication of works on nature. His books include *Historia plantarum* (1686), *Synopsis methodica animalium* (1693), and *Methodus plantarum emendata* (1703). In addition to his scientific books, Ray wrote *A Collection of English Proverbs* (1670) and *A Collection of English Words* (1674).

RAYLEIGH, LORD JOHN WILLIAM STRUTT (1842–1919)

In 1904 the British physicist John Rayleigh received the Nobel Prize in physics for his discovery, in collaboration with Sir William Ramsay, of the noble elementary gas argon. He became involved in his search after reading Prout's hypothesis that all atomic weights should be exact multiples of that of hydrogen. His experiments with the atomic weights of oxygen and hydrogen proved once again the fallacy of Prout's claims; however, it did lead him into his collaboration with Ramsay. He also conducted researches on sound, wave theory, optics, color vision, electrodynamics, electromagnetism, hydrodynamics, viscosity, and photography, as well as electrical measurements and standards.

Lord Rayleigh was born near Maldon, Essex, England, and educated at Trinity College, Cambridge, where he graduated senior wrangler in 1865. From 1879 to 1884 he was head of the Cavendish Laboratory at Cambridge, and in 1887 he became professor of natural philosophy at the Royal Institution of Great Britain.

He was elected a fellow of the Royal Society in 1873, serving as president from 1905 to 1908. In 1902 he became an original recipient of the Order of Merit and in 1905 a privy councilor. His writings include *Theory of Sound* (1877–1878) and *Scientific Papers* (1899–1920).



ESSAYS
BIOGRAPHICAL
AND
CHEMICAL

BY
SIR WILLIAM RAMSAY, K.C.B.
COMMANDEUR DE LA LÉGION D'HONNEUR
COMMENDATORE DELLA CORONA D'ITALIA
FELLOW OF THE ROYAL SOCIETY, ETC.

LONDON
ARCHIBALD CONSTABLE & CO. LTD.
10 ORANGE ST., LEICESTER SQUARE
1908

In addition to discovering the elements known as noble gases, the British chemist Sir William Ramsay was professor of chemistry at University College in Bristol and later at University College in London and wrote several books, including *Essays Biographical and Chemical.*

REED, WALTER (1851–1902)

The U.S. bacteriologist Walter Reed is known primarily for his studies on yellow fever. It was largely due to his efforts that the dread disease was eradicated.

Reed was born at Belroi, Virginia, and educated at the University of Virginia and the Bellevue Hospital Medical College in New York City. On receiving his medical degree in 1870, he set up private practice for a time; but in 1875 he entered the Army Medical Corps as a lieutenant. In 18[illegible] after many years of service, he was appointed professor of bacteriology and clinical microscopy at the Army Medical School in Washington, D.C.

Walter Reed

During the Spanish-American War, there was an outbreak of typhoid fever and yellow fever among U.S. troops serving in Cuba. In 1900 Reed was sent there because yellow fever had reached epidemic proportions. It was then believed that the disease was spread by contact with infected patients, but Reed began study on an earlier theory that it was transmitted by the bite of a mosquito. Because yellow fever was strictly a human disease, only people could be used in the tests. By a series of experiments, in which some of the participants lost their lives, Reed proved that the yellow fever parasite is carried only by the mosquito later classified as *Aëdes aegypti.* A team of U.S. sanitary engineers was then dispatched to Cuba and quickly eradicated the disease by destroying the mosquito breeding grounds. Today yellow fever has been largely eliminated from the world as a result of public health activities.

By a series of experiments on humans, Walter Reed proved that yellow fever is transmitted by the *Aëdes aegypti* mosquito.

Reed was elected to the Hall of Fame for Great Americans in 1945. The Walter Reed Army Hospital in Washington, D.C., is named in his honor.

REGIOMONTANUS. See Müller, Johann.

REICHSTEIN, TADEUSZ (1897–)

The Polish-born Swiss chemist Tadeusz Reichstein shared in the 1950 Nobel Prize in medicine or physiology for discovering the structure and biological effects of the suprarenal cortex hormones. The other winners were E. C. Kendall and P. S. Hench (*See* Philip Showalter Hench; Edward Calvin Kendall.)

Reichstein and his associates isolated twenty-six hormones of the adrenal cortex. One, which Reichstein named Substance Fa, proved to be identical to E. C. Kendall's Compound E, later named cortisone. Reichstein succeeded in producing a partial synthesis of the compound deoxycorticosterone, which was found to prolong the life of animals from which the adrenal gland had been removed and proved also to be the best means at the time for treating Addison's disease (a deficiency of adrenal cortical function). Besides his researches on these steroids, Reichstein synthesized ascorbic acid (vitamin C) independently of Sir W. N. Haworth.

Reichstein was born in Wloclawek, Poland, the son of an engineer, and spent his early years in the Ukraine. The family left Russia in 1905, moving first to Berlin, Germany, and then to Zürich, Switzerland, where they became citizens in 1914. Reichstein obtained his degree in chemical engineering in 1920 and a doctorate in organic chemistry in 1922 at the Federal Institute of Technology, Zürich.

After a period of conducting industrial chemical research, Reichstein held posts from 1930 to 1938 in the Department of Organic Chemistry at the Federal Institute of Technology. In 1938 he became chairman of the Department of Pharmacology and director of the Pharmacological Institute at Basel. In addition, he headed the organic division, including the laboratories.

Reichstein was appointed director of the new Institute of Organic Chemistry in Basel in 1952. With his colleagues in 1953 and 1954, he isolated and explained the structure of aldosterone, a hormone of the adrenal cortex that has a regulatory role in supplying salt and water to the body. Although he retired in 1960, he continued to direct a group of research students. He was elected a foreign associate of the U.S. National Academy of Sciences in 1952.

REYNOLDS, OSBORNE (1842–1912)

The English engineer and physicist Osborne Reynolds gained an international reputation for his work in hydraulics and hydrodynamics. His work on heat transfer, which led to revolutionary changes in the designs of boilers and condensers, and his development of the turbine pump were his greatest achievements. He formulated the theory of lubrication, developed a theory on the law of resistance in parallel channels, and laid the mathematical foundations for studies of turbulence. In addition, he contributed to the idea of group velocity, studied waves and tidal motions in rivers and streams, and explained the radiometer. His activity is responsible for the terms *Reynolds stress* and *Reynolds number*, used in aerodynamics.

Reynolds was born in Belfast, Ireland, and graduated from Queens' College, Cambridge, England, in 1867. The following year he became the first professor of engineering at Owens College, Manchester, England, and stayed there until his retirement in 1905. He was elected to the Royal Society of London in 1877 and received its medal in 1888. His *Scientific Papers* were published in 1900–1903.

RICHARDS, DICKINSON WOODRUFF (1895–)

A share of the 1956 Nobel Prize in medicine or physiology was awarded to Dickinson Richards, U.S. physician and physiologist, for making effective use of cardiac catheterization as a diagnostic tool. He won the prize with his colleague André F. Cournand and the German surgeon Werner T. O. Forssmann, who pioneered the method by passing an opaque catheter through a vein in his arm into the right atrium of his heart and then having his chest x-rayed. (*See* André Frédéric Cournand; Werner Theodor Otto Forssmann.)

Richards was eager to find a way of measuring pulmonary efficiency. By using cardiac catheterization, he was able to assess the flow, pressure, and gas content of blood as it enters the heart from the lungs. The method resulted also in more accurate diagnoses of heart ailments.

Richards was born in Orange, New Jersey, and received his bachelor's degree at Yale University. After serving two years in the U.S. Army during World War I, he earned his master's degree in physiology and his doctorate from Columbia University, New York City. He was on the staff of Presbyterian Hospital in New York City for a period of four years and then went to London, England, to work for a year at the National Institute for Medical Research. Upon his return to Presbyterian Hospital he began to study pulmonary and circulatory physiology. His collaboration with Cournand began in 1931 at Bellevue Hospital, also in New York City, and lasted for more than twenty-five years. In 1945 Richards became professor of medicine and in 1947 Lambert Professor of Medicine at Columbia University. He directed the Columbia medical division at Bellevue Hospital from 1945 until his retirement in 1961. He was elected to the National Academy of Sciences in 1958.

RICHARDS, THEODORE WILLIAM
(1868–1928)

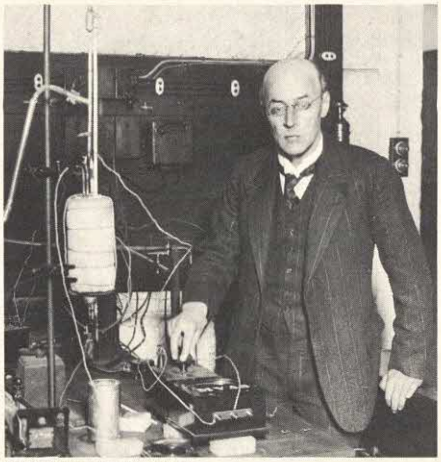
The U.S. chemist Theodore Richards is best known for his atomic weight determinations. In 1914 he received the Nobel Prize in chemistry for his work in this area.

His laboratory investigations and those of his students led to the establishment of the atomic weights of about sixty elements. The atomic weight values of the Belgian chemist Servais Stas had been considered as standard; but Richards revised some of these, lowering, for example, the value of silver from 107.93 to 107.88. Through his investigations of the atomic weight of lead, he was also able to confirm the existence of isotopes. In addition, he introduced the quartz apparatus, the bottling device, and the nephelometer, an instrument for measuring turbidity.

Richards was born at Germantown, Pennsylvania, to an artist father and a poet mother. After graduating from Haverford College in 1885, he did advanced work at Harvard and in Europe. In 1901 he became full professor at Harvard and stayed there the rest of his life. Besides science, his interests included art, music, and literature.

RICHARDSON, SIR OWEN WILLANS
(1879–1959)

Formulation of what has come to be known as the Richardson law, concerning the emission of electrons and ions from heated surfaces, earned the English physicist Owen Willans Richardson the 1928 Nobel Prize in physics. It also established him as one of the founders of atomic physics.



Sir Owen Richardson

The Emission of Electricity from Hot Bodies, written in 1916, describes Richardson's experiments with wireless valves. Rapid advances in radio communication were largely the result of his development of the hard thermionic valve.

Richardson was born in Dewsbury, Yorkshire, England, and educated at Cambridge. In 1906 he moved to the United States to teach physics at Princeton University, in New Jersey, where he remained until 1913, when he returned to England. He devoted the rest of his life to research and to teaching at King's College in London and the University of London. In 1913 he was elected to the Royal Society, and in 1939 he was knighted.

RICHET, CHARLES ROBERT (1850–1935)

The Nobel Prize in medicine or physiology was awarded to the French physiologist Charles R. Richet in 1913 for his work on anaphylaxis, the negative reaction of living organisms to injections of certain foreign proteins. The study of allergic phenomena led this French doctor to his discovery that repeated injections of particular serums over long periods of time could prove fatal to individuals whose systems were hypersensitive.

Richet, the son of a Parisian physician, received his medical degree in 1877. Ten years later he joined the faculty of the University of Paris as professor of physiology. Although his actual vocation was in the field of medicine, Richet also displayed considerable literary talents. As editor of the *Revue Scientifique* from 1887 to 1902, he was able to combine both interests. In his youth he published a volume of poetry under a pseudonym and later wrote several plays and novels. Many of his writings dealt with the subject of pacifism and the problems of achieving and maintaining world peace.

Richet's contributions to the field of allergy study were launched in 1887 when he attempted to produce an immunity serum for tuberculosis sufferers. He injected bacterial substances called antigens into animals so that their systems would produce countermaterial called antibodies; presumably the antibodies would withstand the disease-causing effects of the bacterial antigens. Richet believed that a serum containing antibodies would give humans an immunity to tuberculosis. He first injected such a serum into a tuberculosis patient in 1890 in hopes that it would free the afflicted system of the destructive antigens.

Although his research did not result in a cure for tuberculosis, it did reveal to Richet the potentially dangerous effects of certain injected materials. Often a second dose of a particular antigen into an animal would cause a fatal shock; apparently the antibody produced was to blame. Richet's term for this phenomenon, *anaphylaxis,* is Greek for "without protection."

Prior to his work with antigens and antibodies, Richet investigated the physiology of respiration, the regulation of body heat, and the possibility of treating epilepsy with potassium bromide. His belief that tuberculosis might be cured by feeding the patient raw meat was abandoned in the course of his search for a serum for that disease.

RICKOVER, HYMAN GEORGE (1900–)

The U.S. naval officer and electrical engineer Hyman Rickover achieved prominence as a result of his contribution in developing nuclear propulsion systems for submarines and other naval vessels. His criticism of U.S. educational practices also made him a somewhat controversial figure.

Rickover was born in tsarist Russia but emigrated to the United States with his parents as a child and was reared in Chicago. After graduating from the U.S. Naval Academy, Annapolis, Maryland, in 1922, he entered the naval service, becoming a qualified submariner in 1930. He requested engineering duty in 1937 and enrolled in the U.S. Navy's postgraduate school at Columbia University in New York City, where he received a mas-

Hyman Rickover

ter's degree in electrical engineering. During World War II he was put in charge of the electrical section of the Navy Department's Bureau of Ships.

After the war Rickover received instruction in nuclear physics and engineering at Oak Ridge, Tennessee, and was placed in charge of the navy's nuclear propulsion program. Largely as a result of his efforts, the U.S.S. *Nautilus*, the world's first nuclear-powered submarine, was launched in 1955. He then became chief of reactor research for the Atomic Energy Commission and helped develop the experimental nuclear plant built at Shippingport, Pennsylvania, in 1956–1957. Rickover was made a rear admiral in 1953 and was promoted to the rank of vice admiral in 1959.

For his work in nuclear power and its successful applications Rickover received a gold medal from the U.S. Congress in 1958 and the U.S. Atomic Energy Commission's Enrico Fermi Award in 1964. His publications include *Education and Freedom* (1959), *Swiss Schools and Ours: Why Theirs Are Better* (1962), and *American Education: A National Failure* (1963).

RIEMANN, GEORG FRIEDRICH BERNHARD (1826–1866)

The German mathematician Georg Riemann contributed many theories and methods that widely influenced later studies of mathematics, especially function theory and geometry. His unique approach to geometry made possible the general relativity theory of Albert Einstein.

Riemann was born in Breselenz, Germany, and studied at Berlin and Göttingen, where he obtained his doctorate in 1851. He remained at Göttingen, becoming lecturer in 1853, assistant professor in 1857, and professor in 1859.

The Riemann approach to function theory was based on general principles and geometric ideas rather than on formal calculation. In his new approach to geometry, he studied the properties of a geometric space locally rather than insisting on one overall framework for the entire space. Other contributions included studies of Abelian functions, distribution of primes, and airwaves of finite amplitude. He also gave the first mathematical treatment of shock waves. At least a dozen mathematical concepts and methods bear his name, including Riemannian geometry.

His works were collected and published in 1876. There are also numerous books on his mathematical theories.

ROBBINS, FREDERICK CHAPMAN (1916–)

Together with J. F. Enders and T. H. Weller, the U.S. pediatrician Frederick Robbins won the 1954 Nobel Prize in physiology or medicine for research on the poliomyelitis virus in tissue culture. Development of polio vaccine, new diagnostic methods, and discovery of many new viruses resulted from their work. (*See* John Franklin Enders; Thomas Huckle Weller.)

The three men devised techniques for cultivating the viruses of poliomyelitis in tissue cultures. Until then, technical problems had hampered virologists in their attempts to use tissue culture, and inoculation and observation of experimental animals was a long and unsatisfactory procedure. Robbins and his colleagues succeeded in substituting the test tube for the animals.

Robbins was born in Auburn, Alabama, the son of a plant physiologist who became director of the New York Botanical Garden. After graduating from Harvard Medical School in 1940, he was resident physician in bacteriology and intern in medicine at Children's Hospital, Boston, Massachusetts, for two years. During World War II he became chief of the virus and rickettsial section of the 15th Medical General Laboratory in the Mediterranean area. After the war he returned to Children's Hospital to complete his hospital training in pediatrics. He joined Enders and Weller in 1948 in their research laboratory at the hospital, working there until 1950 as a National Research Council fellow in virus diseases. In 1952 he became director of the Department of Pediatrics and Contagious Diseases at Cleveland (Ohio) Metropolitan General Hospital and professor of pediatrics at Western Reserve University School of Medicine in Cleveland.

ROBINSON, SIR ROBERT (1886–)

For his work with alkaloids, the British chemist Sir Robert Robinson was awarded the 1947 Nobel Prize in chemistry. Although his research was devoted mainly to the structure and synthesis of organic bodies and to the mesomerism theory, he and his colleagues also synthesized the steroid hormones and cholesterol. One of his major scientific contributions was the adumbration of a qualitative electronic theory in organic chemistry. He also studied intramolecular rearrangements, hybrid molecules, and the structure of penicillin and worked on a theory of the biological and abiological origin of petroleum.

Robinson was born near Chesterfield, Derbyshire, England, the son of an inventor and manufacturer. Two years after receiving his doctorate in 1910 from the University of Manchester, he became the first professor of organic chemistry at the University of Sydney, New South Wales, Australia, and stayed there until 1915. Subsequently he held chairs of chemistry at Liverpool (1915–1920), St. Andrew's (1921), Manchester (1922), University College, London (1928), and Oxford (1930–1955). After leaving Oxford he became a consultant and a director of Shell Chemical Company in London.

In 1934 Robinson was elected a foreign associate of the U.S. National Academy of Sciences. He was knighted in 1939 and received the Order of Merit ten years later. From 1945 to 1950 he was president of the Royal Society, and in 1955 he headed the British Association for the Advancement of Science. He was also a recipient of the Copley, Davy, and Royal medals.

ROEBLING, JOHN AUGUSTUS (1806–1869) and WASHINGTON AUGUSTUS (1837–1926)

The U.S. civil engineer John Roebling was a pioneer in the design of modern suspension bridges. Together with his son Washington, he built the Brooklyn Bridge; but, unfortunately, that endeavor was marked by two tragic accidents. One led to his own death, and the second left his son an invalid.

John Roebling was born in Mühlhausen, Germany. After his graduation from the polytechnic school at Berlin, he emigrated to the United States and settled near Pittsburgh, Pennsylvania, where he opened the nation's first wire rope factory.

His first major design was for a suspended aqueduct across the Allegheny River in Pennsylvania. This was followed by a suspension bridge across the Monongahela River at Pittsburgh and by several other structures on the Delaware and Hudson Canal. From 1851 to 1855 he was involved in the design and construction of a long-span wire suspension bridge at Niagara Falls, New York. Because of the success of this bridge, engineers switched from chain cables to wire rope cables in building future suspension bridges. His reputation grew with the design for a suspension bridge across the Ohio River at Cincinnati, Ohio, having a span of 1,057 feet; and he was selected to build the mighty Brooklyn Bridge across the East River in New York City to connect Manhattan and Brooklyn. While overseeing the construction of this bridge, Roebling accidently crushed his ankle. Complications developed, and he fell victim to lockjaw.

John Roebling

Washington Roebling was born in Saxonburg, Pennsylvania. Following in his father's footsteps, he became chief engineer for the completion of the Brooklyn Bridge. While overseeing the building of underwater foundations for the bridge, he was stricken with caisson disease (bends) and never fully recovered. He was able, however, to direct the construction of the bridge by observing the work through field glasses from the window of the room where he was confined as an invalid.

ROENTGEN, WILLIAM CONRAD
(1845–1923)

The first winner of the Nobel Prize in physics (1901) was the German physicist William Roentgen. He received the prize for his discovery of x-rays, or, as they are sometimes called, Roentgen rays. This discovery also won for him the Rumford Medal of the Royal Society in 1896.

Roentgen was born at Lennep, Germany, but studied first in the Netherlands and then in Switzerland, taking his degree at the Zürich Polytechnic in 1866. After working as an assistant at Würzburg and Strasbourg, he was appointed professor of mathematics at Hohenheim in 1875. He was subsequently appointed professor at the universities of Strasbourg (1876), Giessen (1879), Würzburg (1880), and Munich (1900). His main studies were on the compressibility of liquids, the specific heat of gases, and certain aspects of electrodynamics.

While experimenting with a highly exhausted vacuum tube on the conduction of electricity through gases, Roentgen noticed the fluorescence of a nearby barium platinocyanide screen. Investigating further, he found that this radiation passed through various substances opaque to ordinary light and that it also affected photographic plates. Because of its strange behavior, he did not look upon it as ordinary transversely vibrating light and guessed that it was due to longitudinal vibrations. He called these radiations, which he discovered in 1895, x-rays.

Roentgen's discovery fascinated not only scientists but also the general public. In a century when only ordinary light was known and the existence of infrared and ultraviolet radiations had barely been revealed, the discovery of a radiation that could penetrate through the human body, among other things, and render it transparent to the eye was something really extraordinary. There were some doubts, however, about the implications of Roentgen's discovery. Some people, for instance, considered that the x-rays were a threat to modesty. In New Jersey a law was passed prohibiting the use of x-rays in opera glasses lest they be used to see through clothes, and a London firm advertised x-ray proof underwear.

Roentgen spent the two years following the announcement of his discovery studying the properties of the new radiation. He found that it was invisible even though it had the property of rendering certain fluorescent substances luminous when it came in contact with them; that it exposed a photographic plate; and that it traveled in a straight line. Moreover, the substance with which it came in contact also emitted radiation, and the air through which it passed became a conductor of electricity.

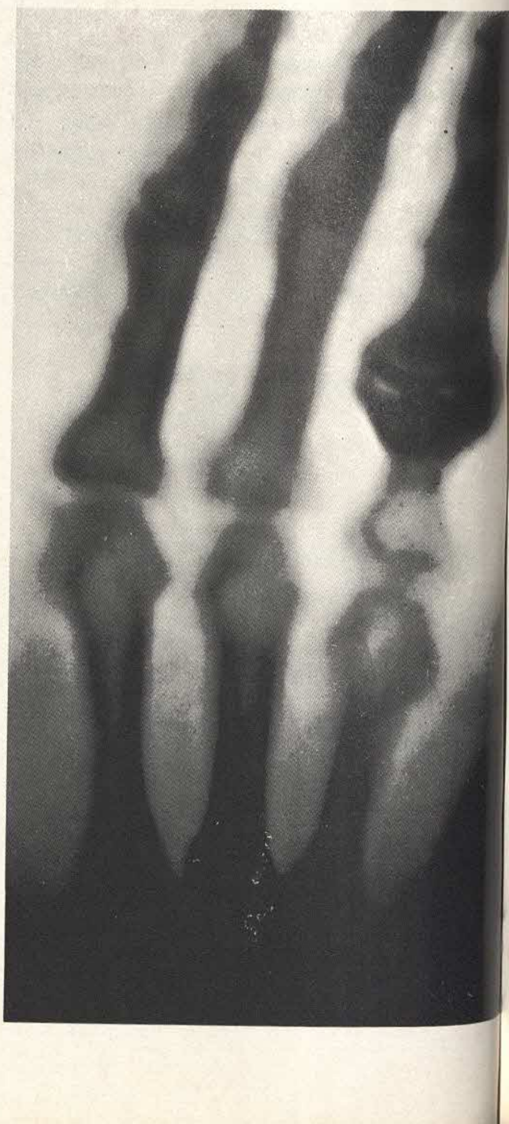
Roentgen's discovery and his subsequent studies paved the way for a great number of practical applications in the field of science and technology. The discovery provided physicists with an extremely effective means of research. The new radiation allowed them to acquire a thorough knowledge of the structure of the atom and to understand the distribution of its component elements. It enabled them to see that radiation can behave like a material particle striking another particle and to discover that it conveys energy in clearly defined and separate quantities.

Almost immediately after the discovery it was realized that x-rays could prove extremely useful in medical investigation. The use of x-rays spread rapidly in the diagnoses of diseases of the bones and internal organs. Soon, however, it became apparent that the new radiation concealed a dire peril. Its use without adequate protection caused permanent damage to tissue that had been exposed to it. Many doctors suffered mutilation and even death, often from leukemia, as a result of exposure to x-rays.

Roentgen received many well-deserved honors, but he gained no financial benefits from his discovery. He spent the last years of his life continuing his research

William Roentgen

Shortly after their discovery in 1895, x-rays were used to photograph the hand of William Roentgen's wife. Her ring showed up clearly and made the x-ray easily identifiable.



on x-rays and on many other subjects, such as crystallography, infrared radiation, elasticity, and capillarity.

ROMER, ALFRED SHERWOOD (1894–   )

The U.S. zoologist and paleontologist Alfred Romer is known for his contributions to the evolutionary history of vertebrates. For his work in vertebrate paleontology, he received many awards and honors.

Romer's early work was in muscle evolution and embryological differentiation. His later research was concentrated on the evolutionary history of animals as revealed in fossil records. When he was a professor at the University of Chicago, he became interested in the fossils of the early Permian period and made a study of pelycosaurs, a group of reptiles involved in mammal evolution, and traced the evolutionary history from the reptiles down through the amphibians to the ancestral fish types.

The discovery of a skull in the Southwest in the 1920s led to Romer's conclusion that many of the great animals, such as elephants and sloths, lived in North America until relatively recently. Romer also made explorations in the Carboniferous beds of the Appalachians and Canada and was a member of two expeditions to Argentina to study Triassic fauna.

Romer was born at White Plains, New York, and educated at Amherst College in Massachusetts, from which he graduated in 1917. After receiving his doctorate from Columbia in New York City in 1921, he took up a career of teaching: anatomy at New York University Medical School (1921–1923), vertebrate paleontology at the University of Chicago (1923–1934), and zoology at Harvard (after 1934), where he also was curator of vertebrate paleontology and director of the Museum of Comparative Zoology (1946–1961). Romer became professor emeritus in 1965.

He was elected to the National Academy of Sciences in 1944. His awards included the Thompson and Eliot medals of the National Academy of Sciences (1954 and 1956), the Hayden Memorial Geological Award of the Academy of Natural Sciences of Philadelphia (1962), and the Penrose Medal of the Geological Society of America (1962). Among his works are *Vertebrate Paleontology* (1933), *Man and the Vertebrates* (1933), *The Vertebrate Body* (1949), *Osteology of the Reptile* (1956), and *The Vertebrate Story* (1959).

RÖNTGEN, WILHELM CONRAD.

See Roentgen, William Conrad.

ROSS, SIR JAMES CLARK (1800–1862)

The British rear admiral and explorer Sir James Clark Ross, who carried out important magnetic surveys of the Arctic and Antarctic regions, was born in London, England. As a member of the Royal Navy, he accompanied his uncle Captain John Ross on the latter's first Arctic voyage in 1818. The next nine years were spent with Sir William Edward Parry on his four Arctic expeditions, and from 1829 to 1833 he again accompanied his uncle, reaching the North Pole in 1831.

Sir James Ross

During an Antarctic voyage to conduct observations and reach the South Pole (1839–1843), he discovered the Ross Sea and Victoria Land. Impeded by the Ross ice shelf, he returned to Hobart for the winter but continued the voyage the following November, probably sighting Edward VII Peninsula and later charting Graham Coast. During intermittent periods, Ross spent time searching for missing ships—in 1836 he searched for missing whaling ships, and from 1848 to 1849 he looked for Sir John Franklin in H.M.S. *Enterprise* and *Investigator.*

His *Voyage of Discovery . . . in the Southern and Antarctic Regions* was published in 1847. He was elected a fellow of the Royal Society in 1848.

ROSS, SIR RONALD (1857–1932)

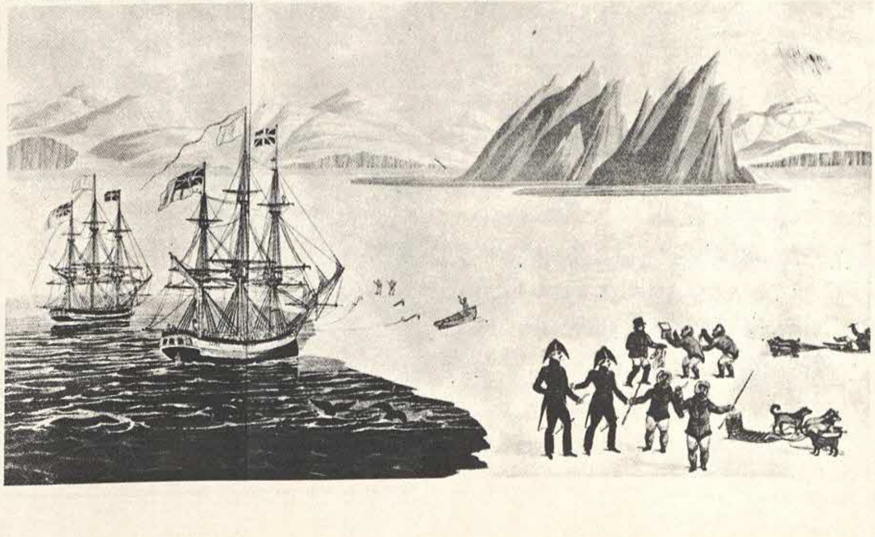
While serving as a young doctor in the Indian Medical Service, the British physician Ronald Ross became interested in the theory that mosquitoes transmit malaria. His subsequent research and his discovery of the malarial parasite harbored in the anopheles mosquito earned him the 1902 Nobel Prize in medicine or physiology.

Ross, the son of an Indian army officer, was born at Almora, India. When he was eight years old, he traveled to England and there received his education, including a medical degree from St. Bartholomew's Medical School. In 1881 he returned to India, where he began his lifelong fight to curb tropical disease.

In addition to his responsibilities as an Indian Medical Service physician, Ross assumed the task of locating the malarial parasites in the bodies of mosquitoes. After collecting, feeding, and dissecting the insects for several years, he was able to identify cysts on the stomach wall of certain mosquitoes as one stage of the life cycle of the malaria parasite. Since his obligations to the Indian military prevented him from tracing this parasite to its development in human victims, he turned his attention to birds suffering from malaria. In 1897, when he discovered the parasite in the salivary glands of certain mosquitoes that had fed on infected birds, he realized that these insects were transmitting the fever from diseased birds to healthy ones. He thereby provided the key that would later unlock the door to a preventive for human malaria.

Upon returning to England in 1899,

An event of the 1818 Arctic voyage that James Ross made with his uncle Captain John Ross is depicted in a print of the time, which records their meeting with Eskimos. Never having seen such a large ship, the Eskimos asked whether they had come from the sun or the moon.



In his fight against malaria, the British physician Ronald Ross pursued the theory of its transmission by mosquitoes and spent a period of several years conducting research that involved, among other things, dissection of the insects.

Sir Ronald Ross

Ross joined the faculty of the Liverpool School of Tropical Medicine as a lecturer and later the University of Liverpool as professor of tropical medicine. In 1913 he accepted a position at King's College Hospital in London as a physician of tropical diseases. During World War I he was a consultant on malaria in the War Office and afterward held the same position for the Ministry of Pensions.

Sir Ronald Ross was not only a prominent bacteriologist but also the author of poems, novels, plays, and mathematical studies. Knighthood was bestowed on him in 1911.

ROUS, FRANCIS PEYTON (1879–1970)

The U.S. research scientist Francis Peyton Rous shared the 1966 Nobel Prize in medicine or physiology with Charles B. Huggins. Working independently, both men made revolutionary discoveries in early cancer research. (*See* Charles Brenton Huggins.)

Rous's major discovery began in 1909 when a hen with breast cancer was brought to him. He set out to determine the specific agent that was known to carry the infection from one hen to another and in 1910 concluded that the malignant growths were caused by a virus. His work was scoffed at for years; but later, as other forms of cancer in animals proved to be viral, his thesis was vindicated. Researchers continued to investigate the possibility that this might also be true of some of the specific forms of the disease that attack humans.

Rous also made pioneer discoveries in obtaining information concerning the gallbladder and liver. His research on the preservation of whole blood for transfusions made the first blood banks possible.

Francis Rous

He was born in Baltimore, Maryland, and in 1905 graduated in medicine from Johns Hopkins University there. In 1909, after working as an instructor in pathology at the University of Michigan, he joined the Rockefeller Institute for Medical Research (now Rockefeller University) in New York and remained there throughout his career, becoming a member in pathology and bacteriology in 1920.

In 1927 Rous was elected to the National Academy of Sciences and in 1956 received its Kovalenko Medal. His many other honors included the 1958 Lasker Award of the American Public Health Association and the 1966 National Medal of Science.

RUMFORD, COUNT. See Thompson, Benjamin.

RUSH, BENJAMIN (1745–1813)

The U.S. physician and medical educator Benjamin Rush, prominent during the revolutionary period, was instrumental in the rise of U.S. medicine. He introduced clinical instruction at the Pennsylvania Hospital in Philadelphia and started a dispensary in that city. Active in the cause of the colonies, he was also one of the signers of the Declaration of Independence and served briefly as surgeon general of the army.

Rush was born on a farm near Philadelphia to a Quaker family and at age fifteen obtained his bachelor's degree from the College of New Jersey (now Princeton University). After six years as a medical apprentice in Philadelphia, he went to the University of Edinburgh, Scotland, for further study, receiving his medical degree there in 1768. The following year, having returned to the colonies, he became professor of chemistry at the College of Philadelphia (later merged with the University of Pennsylvania) and in 1791 professor of the institutes of medicine and clinical practices at the University of Pennsylvania.

He had great powers of observation and wrote excellent descriptions of yellow fever, cholera infantum, dengue, and rheumatism. His medical study on mental diseases, published in 1812, was the first systematic American book on the subject. A believer in bloodletting and purging, however, he unfortunately sometimes enfeebled his patients.

In addition to his medical activities, Rush was involved in the struggle for independence and wrote on many subjects, including numerous social reforms: better conditions for prisoners and mental patients, higher education for women, and public schools. In 1797 President John Adams appointed him treasurer of the national mint in Philadelphia, and he held that office for the remainder of his life.

RUSSELL, BERTRAND ARTHUR WILLIAM RUSSELL, THIRD EARL (1872–1970)

The English mathematician and philosopher Bertrand Russell was noted as much for his views on society as for his contributions to the mathematical world. His interests were many; and in addition to his other talents, he was a prolific writer. When he won the 1950 Nobel Prize, it was not in any of the sciences but in literature.

In the field of mathematics Russell attempted to set up a superior system of logic, making pure mathematics totally rigorous. This was an ambitious project but one doomed to failure. In 1903 he published *The Principles of Mathematics;* in 1919, his *Introduction to Mathematical Philosophy*. Along with A. N. Whitehead, he wrote *Principia Mathematica* in three volumes. He also wrote popular scientific books, such as *The A.B.C. of Atoms* (1923) and *The A.B.C. of Relativity* (1926).

Russell was born at Trelleck, Monmouthshire, to a prestigious English family. Orphaned at age three, he was raised by his grandparents. His paternal grandfather, John Russell, was the prime minister of Great Britain from 1846 to 1852 and from 1865 to 1866, and in 1861 became the first earl Russell. The title was handed down to Bertrand, who became the third earl in 1931. Young Russell received his early education from private tutors and in 1890 entered Trinity College, Cambridge, becoming a fellow of the college in 1895. After serving in the British diplomatic corps and studying political philosophy in Germany, he returned to Cambridge in 1910 as a lecturer.

Bertrand Russell

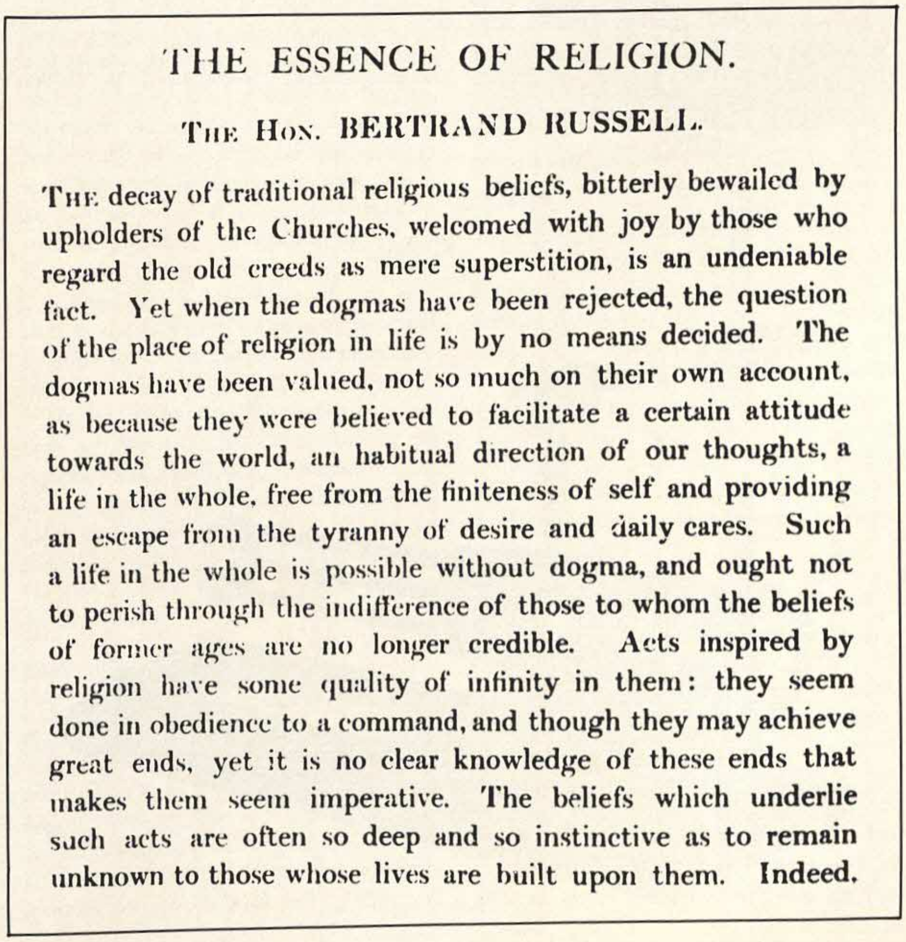
Russell's political views colored every facet of his life. He was a staunch liberal and an adamant pacifist. Because of this stand during World War I, he was fired from his university post in 1916 and also spent some time in prison. In 1938 he went on a lecture tour in the United States but ran into difficulties because of his liberal views on morality. An appointment at the City College of the City of New York was withdrawn in 1940, and a lecture contract was canceled in 1943. The following year he returned to England. During the so-called cold war of the 1950s he resumed his neutral but vocal pacifist stand and in 1961 was again imprisoned for a short time.

Besides his books on mathematics and science, he also published works on philosophy and politics. In 1908 he was elected to the Royal Society, and in 1949 he was awarded the Order of Merit.

RUSSELL, HENRY NORRIS (1877–1957)

The U.S. astronomer Henry Russell was co-inventor of the Hertzsprung-Russell diagram, a major contribution to the development of modern stellar astronomy and astrophysics. It illustrates the relationship between the spectral types and absolute magnitudes of the stars. He also developed a system for determining dimensions of double stars the components of which periodically eclipse each other, and he and Ejnar Hertzsprung independently found a way to determine the dis-

Bertrand Russell was a prolific writer, publishing works on philosophy as well as on science.



THE ESSENCE OF RELIGION.

THE HON. BERTRAND RUSSELL.

THE decay of traditional religious beliefs, bitterly bewailed by upholders of the Churches, welcomed with joy by those who regard the old creeds as mere superstition, is an undeniable fact. Yet when the dogmas have been rejected, the question of the place of religion in life is by no means decided. The dogmas have been valued, not so much on their own account, as because they were believed to facilitate a certain attitude towards the world, an habitual direction of our thoughts, a life in the whole, free from the finiteness of self and providing an escape from the tyranny of desire and daily cares. Such a life in the whole is possible without dogma, and ought not to perish through the indifference of those to whom the beliefs of former ages are no longer credible. Acts inspired by religion have some quality of infinity in them: they seem done in obedience to a command, and though they may achieve great ends, yet it is no clear knowledge of these ends that makes them seem imperative. The beliefs which underlie such acts are often so deep and so instinctive as to remain unknown to those whose lives are built upon them. Indeed, tances from the solar system of double stars observed through a telescope to be in revolution about their common center of gravity.

Russell was born at Oyster Bay, New York. After attending Princeton University, he went to Cambridge, England, where he worked in determining stellar parallaxes by photography, a system then still new. On his return to Princeton in 1905, he began extensive work in modern astronomy and spectroscopy.

His writings include *Modifying Our Ideas of Nature: The Einstein Theory of Relativity* (in the *Smithsonian Report for 1921*), *The Constitution and Evolution of the Stars* (in the *Smithsonian Report for 1923*), *The Composition of the Stars* (1933), *The Atmospheres of the Planets* (in the *Smithsonian Report for 1935*), and *The Solar System and Its Origin* (1935).

RUTHERFORD, SIR ERNEST (1871–1937)

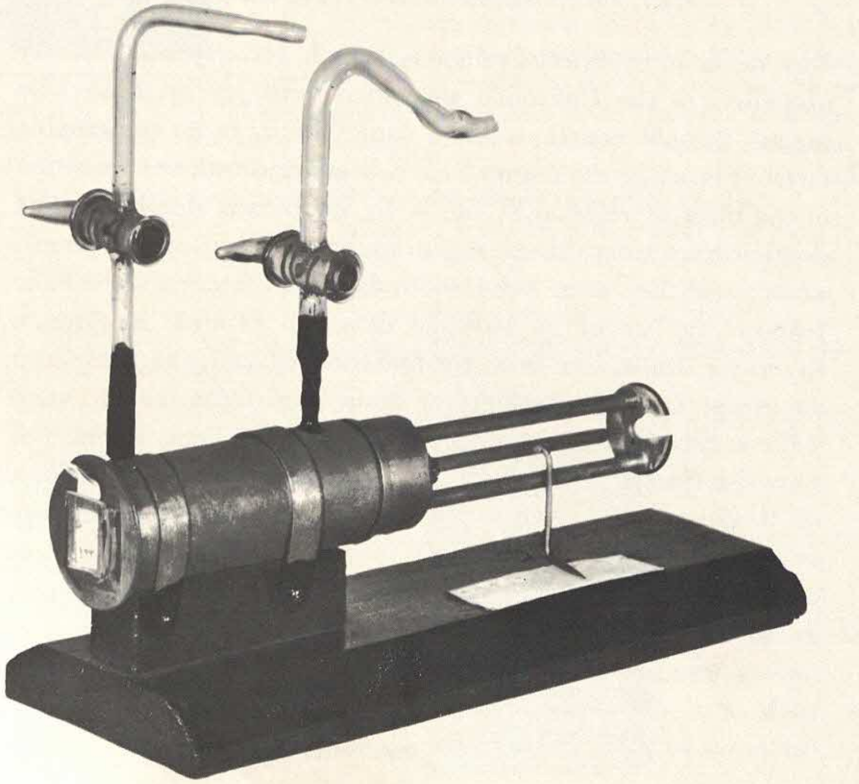
The 1908 Nobel Prize in chemistry was awarded to Ernest Rutherford, the British physicist whose researches in radiation and atomic structure provided the basis for modern developments in nuclear physics. His interest in radioactivity led to research that resulted in the discovery of alpha, beta, and gamma rays. In collaboration with Frederick Soddy at McGill University, Montreal, Canada, he set forth a modern theory of radioactivity; and after World War I he successfully transmuted nitrogen into an isotope of oxygen by bombarding the nitrogen with alpha particles.

Sir Ernest Rutherford

Rutherford was born at Nelson, New Zealand. After taking his master's at Canterbury University College, Christchurch, he received a scholarship to Cambridge in England, where his ability was soon recognized by J. J. Thomson at the Cavendish Laboratory. In 1898 he joined the faculty of McGill University; in 1907 he accepted the Langworthy Professorship at Manchester University in England; and in 1919 he moved to Cambridge, succeeding Thomson at Cavendish Laboratory.

Knighthood was bestowed on him in 1914, and in 1931 he was created the first baron Rutherford of Nelson and Cambridge. In 1923 he served as president of the British Association for the Advancement of Science and in 1925 of the Royal Society, the Copley Medal of which he won in 1922. His writings include *Radioactive Substances and Their Radiations* and, together with J. Chadwick and C. Ellis, *Radiations from Radioactive Substances* (1930).

By helping the British physicist Ernest Rutherford in his research on radiation and atomic structure, this instrument, though simple and rudimentary, was of fundamental value to later twentieth-century developments in nuclear physics.



RUZICKA, LEOPOLD (1887–   )

For his work on polymethylenes and higher terpenes, the Swiss chemist Leopold Ruzicka shared the 1939 Nobel Prize in chemistry with Adolf Butenandt. Ruzicka's findings led to the first production of synthetic male sex hormones. (*See* Adolf Friedrich Johann Butenandt.)

Ruzicka was the first chemist to synthesize musk, the substance responsible for the peculiar odor given off by the musk deer, and he also synthesized civet. The importance of this work was the discovery that musk consists of a fifteen-membered ring of carbon atoms, and civet of a seventeen-membered ring. Up to that time it had been believed that rings containing more than eight carbon atoms would be too unstable to exist. Ruzicka's findings opened up a whole new area of organic chemistry.

He did a great deal of important research on organic synthesis, proceeding mainly on the hypothesis that complicated molecules are based on aggregations of isoprene molecules. His synthesis of the hormones androsterone and testosterone from neutral cholesterol in 1934 and 1935 was the direct result of his studies of the chemical structure of the sterols. These synthetic hormones became important in the treatment of functional sexual disorders.

Ruzicka was born at Vukova, Yugoslavia, then a part of Austria-Hungary. He was educated in Germany, graduating from the Technische Hochschule at Karlsruhe in 1910. Two years later he went to Switzerland and eventually became a Swiss citizen. In 1926 he became professor of organic chemistry at the University of Utrecht in the Netherlands; and from 1929 until his retirement in 1957, he was professor at the Swiss Federal Institute of Technology in Zürich.

SABATIER, PAUL (1854–1941)

A French chemist whose researches in catalytic organic synthesis had important industrial applications, Paul Sabatier shared the 1912 Nobel Prize in chemistry with another French chemist, F. A. V.

Grignard. Sabatier's discoveries formed the basis of the margarine, oil hydration, and synthetic methanol industries. He is known particularly for discovering the use of nickel in hydrogenation, which is the addition of hydrogen to molecules of carbon compounds. (*See* François Auguste Victor Grignard.)

In the 1890s Sabatier began to concentrate on the catalytic effect of inorganic compounds, such as finely divided metals, on organic gas-phase reactions. He found that finely divided nickel catalyzes the hydrogenation of acetylene and ethylene to ethane and catalyzes the hydrogenation of benzene to cyclohexane. Until this discovery platinum or palladium was used routinely as the catalyst for hydrogen additions. (A catalyst speeds the rate of a chemical reaction and remains unchanged chemically throughout that reaction.) The comparatively inexpensive nickel made hydrogenations practical on a large industrial scale.

Sabatier was born in Carcassonne, and studied chemistry at the École Normale Supérieure and the Collège de France, earning his doctorate in 1880. Two years later, after teaching at Bordeaux, Sabatier went to the University of Toulouse, where he was made a professor in 1884 and became dean in 1905. Despite an offer from the University of Paris in 1907, he chose to stay in southern France until his retirement.

Sabatier proceeded to explore nearly the whole field of catalytic synthesis and wrote on his theories in *La Catalyse en Chimie Organique* (1912). He was elected to the French Academy of Sciences in 1913.

SABIN, ALBERT BRUCE (1906–)

The Polish-born U.S. physician Albert Sabin, outstanding virologist, developed the first successful oral vaccine for poliomyelitis. In addition, he made extensive contributions to the knowledge of encephalitis, sand-fly fever, and dengue; and in the 1960s he turned his attention to the role that viruses play in human cancer.

Sabin began his study of viruses while he was at New York University and early was able to grow polio virus in human tissue outside the body. After working with monkeys, he developed a usable oral vaccine and conducted tests on human volunteers from a federal reformatory in Chillicothe, Ohio (1954–1957). Public tests began in 1958 on thousands of schoolchildren in Czechoslovakia and Malaya, and the following year the tests were expanded to include hundreds of thousands of children in the Soviet Union and Mexico. They proved so successful that the Soviet government authorized public distribution of the vaccine. The U.S. government approved the vaccine in 1961, and a year later it was licensed for general use.

Albert Sabin

In other areas, Sabin investigated pneumococcus infections, isolated the B virus (which can be fatal to humans) in the monkey, and studied many viruses affecting the human nervous system. He also discovered many new viruses in the human alimentary tract (habitat of the polio virus) and proved that they were the causes of such diseases as aseptic meningitis, rare paralyses, and infantile diarrhea.

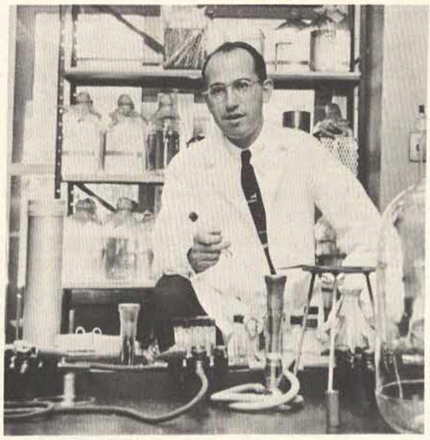
Sabin was born in Bialystok, Poland, but emigrated to the United States in 1921. He studied at New York University, receiving his medical degree in 1931. After training for a year at Bellevue Hospital in New York City, he did research at the Lister Institute of Preventive Medicine in London and then joined the staff of the Rockefeller Institute for Medical Research (Rockefeller University) in New York City, where he served as an assistant until becoming an associate in 1937. Two years later he was named associate professor of pediatrics at the University of Cincinnati's medical school and head of the infectious disease division at the Children's Hospital Research Foundation there. He was appointed professor of research pediatrics in 1946.

He was elected to the National Academy of Sciences in 1951. Among his honors were the Bruce Memorial Award of the American College of Physicians (1961), the Feltrinelli Prize of the Accademia Nazionale dei Lincei of Rome (1965), and the Lasker Clinical Science Award (1965).

SALK, JONAS EDWARD (1914–)

Developer of a vaccine against poliomyelitis, the U.S. physician Jonas Salk was responsible for eradicating the crippling disease as a public health menace. Using monkeys, he developed and perfected a killed-virus vaccine against paralytic poliomyelitis. It proved effective in tests on schoolchildren in 1954, and the following year the U.S. Public Health Service authorized its manufacture and widespread use. By the 1960s polio was all but eliminated as a threat; a check showed a reduction of 96 percent in polio cases in the United States as compared with a five-year period before the Salk vaccine was introduced.

Salk was born in New York City and studied at the City College of the City of New York and at New York University, where he obtained his medical degree in 1939. After his internship he became a researcher at the University of Michigan, Ann Arbor, where he helped develop a successful influenza vaccine. In 1947 he became research professor of bacteriology and director of the virus research laboratory at the University of Pittsburgh in Pennsylvania, in 1957 he became professor of experimental medicine there, and in 1962 he became director and president of the Salk Institute for Biological Sciences in San Diego, California. Salk was presented the Lasker Award of the American Public Health Association in 1956 and the Bruce Memorial Award of the American College of Physicians in 1958.


Jonas Salk

SANGER, FREDERICK (1918–)

The English chemist Frederick Sanger was awarded the 1958 Nobel Prize in chemistry for determining and establishing the amino acid sequence for a protein. In 1943 he began his investigations and by 1955 was able to ascertain the exact order of the amino acids in insulin. This discovery was a breakthrough for the determination of protein structure in general and was a prerequisite for the chemical synthesis of insulin that was accomplished by other scientists in 1964.

Sanger was born at Rendcombe, Gloucestershire, England, the son of a doctor. He was educated at St. John's College, Cambridge, receiving his bachelor's degree in 1939 and his doctorate in 1943. The following year he became a fellow of the Medical Research Council at Cambridge and stayed in that post until 1951, when he became head of the Division of Protein Chemistry in the council's Laboratory for Molecular Biology there. In 1951 he was awarded the Corday-Morgan Medal of the Chemical Society, and in 1954 he was elected a fellow of the Royal Society.

SCHEELE, CARL WILHELM (1742–1786)

During his relatively short lifetime the Swedish chemist Carl Scheele probably discovered more substances than any scientist who preceded or followed him. He is most famous, however, for his isolation of oxygen, which he accomplished independently of Joseph Priestley.

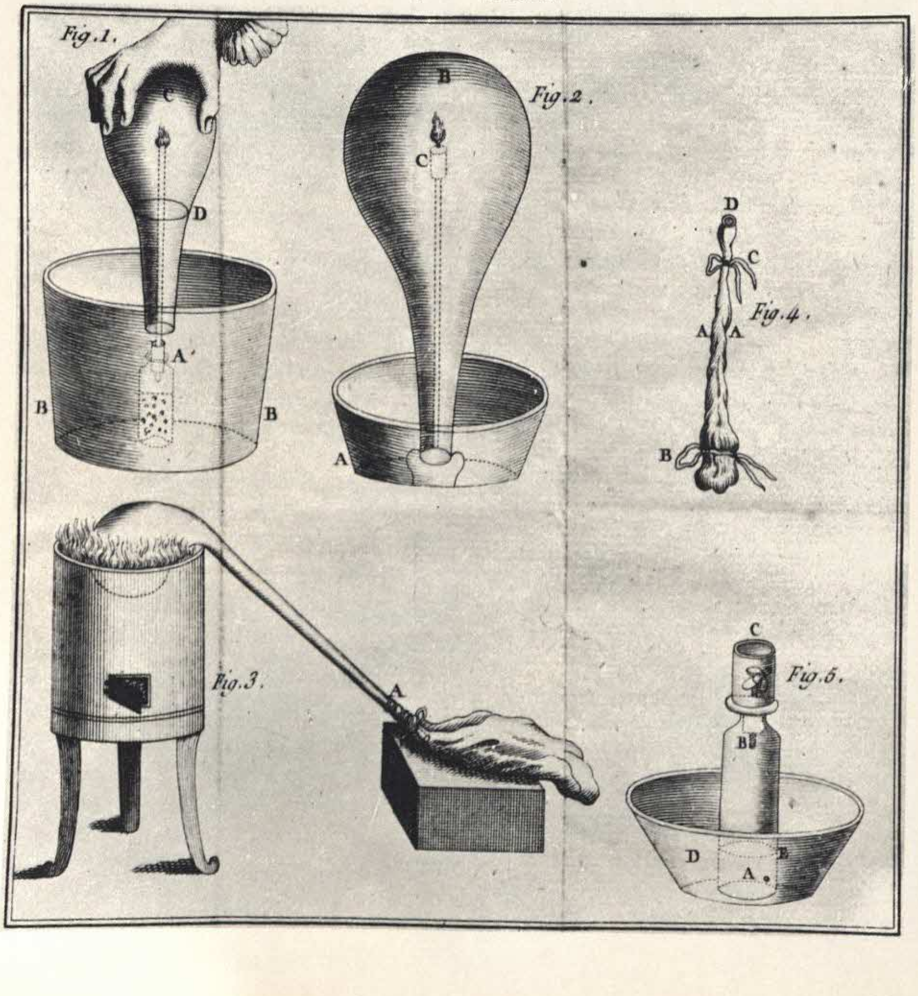
Some of his claims of discovery met with opposition. He maintained that he had obtained oxygen a year or two before Priestley; but since he did not publish the results until 1777, he is seldom given credit for it. In connection with this work, Scheele found that air is composed of two gases. One he called fire air (oxygen) because it burned, and the other he called foul air. He prepared oxygen by heating certain substances, such as potassium nitrate, nitric acid, and manganese dioxide.

Scheele isolated chlorine but failed to recognize it as an element. Other elements that he shared in the discovery of were barium, manganese, molybdenum, nitrogen, and tungsten. Among the compounds he discovered were arsenic acid, benzoic acid, citric acid, gallic acid, mallic acid, molybdic acid, oxalic acid, hydrogen sulfide, and copper arsenite (known as Scheele's green); and he prepared uric acid from bladder stones. Such poisonous gases as hydrogen fluoride and hydrogen cyanide also came under his scrutiny. His habit of smelling and tasting the substances that he was studying could have been responsible for his untimely death: the symptoms of his final illness resembled those of mercury poisoning.

Scheele was born at Stralsund, Pomerania (then part of Sweden). In 1757 he was apprenticed to an apothecary in Göteborg, Sweden, and during his apprenticeship became an enthusiastic student of chemistry. Although he was offered two prestigious professorships, one in Germany and one in England, he preferred to remain an apothecary all his life, devoting his free time to research. In 1775 he was elected a member of the Swedish Royal Academy of Sciences.

Carl Scheele

A plate from Carl Scheele's only book, *Air and Fire* (1777), illustrates some of his experiments to determine the nature of air. According to this book, one-fourth of the atmosphere is fire air, or oxygen, and the rest is foul air, or nitrogen.



SCHIAPARELLI, GIOVANNI VIRGINIO (1835–1910)

The Italian astronomer Giovanni Schiaparelli was interested mainly in study-

Using a Merz telescope, Giovanni Schiaparelli completed one part of his study of the planet

ing the solar system and made important observations regarding comets, meteors, and especially the planet Mars. Late in life he became a historian of ancient astronomy. He was also a senator of the kingdom of Italy.

In 1861 he made his first major observation [illegible] the discovery of the asteroid Hesperia; and in 1866 he showed that meteor swarms travel in cometary orbits and recorded important information regarding the identity and orbits of comets in the Leonid and Perseid showers. He also observed many double stars and published his findings in two volumes.

Perhaps his most famous work was his observation of the planet Mars. In 1877 he [illegible] the direction of the axis of rotation and the position of the southern polar cap of Mars, but most importantly he observed what he called *canali,* or channels. This was the first observation of the famous Martian canals, and it touched off speculations and controversies that continue to the present day.

Schiaparelli was born at Savigliano, Piedmont, and studied mathematics and physics at the University of Turin. After graduating in 1854, he studied astronomy in Berlin, Germany, and in Russia. In 18[illegible] he returned to Italy and became an assistant observer at the Brera Observatory in Milan, serving as its director from 1862 to 1900. On his retirement he studied the history of Babylonian, Greek, and Hebrew astronomy.

M[illegible] thereby achieving for himself a foremost place among astronomers.

SCHLIEMANN, HEINRICH (1822–1890)

For his extensive excavations at Troy, Mycenae, and Tiryns, the German archaeologist Heinrich Schliemann has been called the modern discoverer of prehistoric Greece. Settling in Greece in 1868, he began archaeological investigations at Ithaca and Mycenae and uncovered royal tombs and a wealth of other great treasures. Of the many ruins uncovered by him, he is most famous for those that he claimed to be ancient Troy.

When his workmen had excavated the ruins of Troy, Heinrich Schliemann spent hours making sketches of the remains.

Schliemann was born at Neu Buckow in Mecklenburg-Schwerin and at age fourteen was apprenticed to a grocer. Because of poor health, however, he became a cabin boy; but his ship was soon wrecked, and he found employment as a bookkeeper in Amsterdam, the Netherlands. During this time he kept up with his studies, mastering more than a dozen languages. In 1846 his Dutch employers sent him to St. Petersburg, Russia, where he established his own business a year later and soon became very wealthy. After retiring from business at thirty-six, he pursued his interest in ancient Greece and undertook extensive travels to Greece, Egypt, the Near and Far East, and North America. In 1866 he went to Paris to study archaeology and dedicated himself to fulfilling his boyhood dream of excavating Troy.

SCHRÖDINGER, ERWIN (1887–1961)

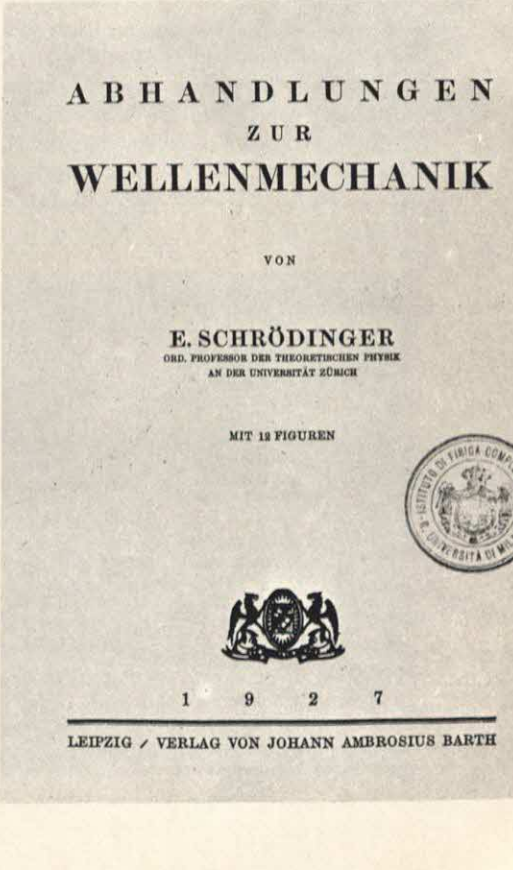
One of the founders of quantum mechanics was the Austrian physicist Erwin Schrödinger, who developed the concept of atomic structure based on wave mechanics. He worked out an equation to explain the quantum behavior of such particles as electrons. For his work in this area he shared the 1933 Nobel Prize in physics with Paul Dirac. (*See* Paul Adrien Maurice Dirac.)

After learning of the matter waves and the theory of the wave characteristics of electrons conceived by Louis de Broglie, Schrödinger began working out a mathematical basis for De Broglie's ideas and in 1926 published the results of his investigations into wave mechanics. Centering his work around De Broglie's idea that the use of a wave field was necessary to describe the behavior of electrons and other particles, Schrödinger formulated a complete theory on this basis, expressed by what is commonly known as the Schrödinger wave equation. His theory was mathematically equivalent to the matrix mechanics worked out by W. K. Heisenberg.

Schrödinger extended De Broglie's theory of wave mechanics to the problem of atomic structure by assuming that matter waves could be superimposed on one another. He also studied radium and made important contributions to the theory of color.

Schrödinger was born in Vienna and received his education at the university

In his work *Study on Wave Mechanics* (1927), Erwin Schrödinger set forth some of his concepts relating to this field of physics.



ABHANDLUNGEN
ZUR
WELLENMECHANIK

VON

E. SCHRÖDINGER
ORD. PROFESSOR DER THEORETISCHEN PHYSIK
AN DER UNIVERSITÄT ZÜRICH

MIT 12 FIGUREN

ISTITUTO DI FISICA COMPLEMENTARE · UNIVERSITÀ DI MILANO

1927

LEIPZIG / VERLAG VON JOHANN AMBROSIUS BARTH there. After World War I, in which he served as an artillery officer, he went to Germany, where he soon was appointed professor of physics at the University of Stuttgart. Subsequently, he taught physics at Breslau and at the University of Zürich, Switzerland, and in 1927 succeeded Max Planck as professor of theoretical physics at the University of Berlin. When Hitler came to power, Schrödinger left Germany and went to England, accepting an invitation from Oxford. In 1936 he returned to Austria; but on the Nazis' rise to power, he went to Ireland, where he became professor at the Institute for Advanced Studies in Dublin. He remained there until 1957, when he returned once more to Vienna.

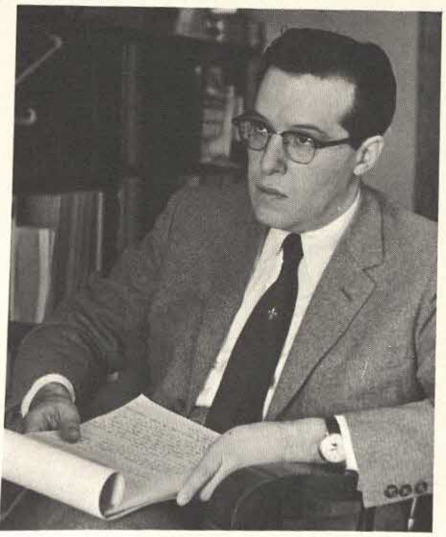
Erwin Schrödinger

SCHWINGER, JULIAN SEYMOUR

(1918–   )

For experiments in quantum electrodynamics conducted during World War II, the Harvard University physicist Julian Schwinger shared the 1965 Nobel Prize in physics with R. P. Feynman and Shin'ichero Tomonaga. The three engaged in similar but independent research. (*See* Richard Phillips Feynman; Shin'icherō Tomonaga.)

Julian Schwinger



Schwinger was born in New York City and educated at Columbia University. After receiving his doctorate in 1939, he went to the University of California, where he became associated with the U.S. physicist J. Robert Oppenheimer. At age twenty-eight Schwinger joined the Harvard faculty as associate professor of physics, and the following year became full professor, one of the youngest in the school's history.

In 1949 Schwinger was elected to the National Academy of Sciences and in 1951 was a co-winner of the Albert Einstein Award in natural sciences. He was editor of *Quantum Electrodynamics* and a member of the Board of Sponsors of the *Bulletin of the Atomic Scientists.*

SEABORG, GLENN THEODORE

(1912–   )

For his work on the transuranium elements the U.S. physical chemist Glenn Seaborg shared the 1951 Nobel Prize in chemistry with Edwin M. McMillan, with whom he collaborated on isolating plutonium. After the discovery of the first transuranium element by McMillan in 1940, it was only a short time until the element corresponding to atomic number 94, plutonium, was discovered by Seaborg, together with McMillan. (*See* Edwin Mattison McMillan.)

Between 1940 and 1955 Seaborg succeeded in isolating eight transuranium elements, including plutonium. He synthesized americium (atomic number 95) and curium (atomic number 96) in 1944, and berkelium (atomic number 97) and californium (atomic number 98) in 1949. Between 1952 and 1955 he synthesized the transuranium elements corresponding to atomic numbers 99, 100, and 101: einsteinium was named in honor of Albert Einstein; fermium, in honor of Enrico Fermi; and mendelevium, in honor of Dimitry Ivanovich Mendeleeff. Seaborg recognized that the transuranium elements comprise an actinide series and that these elements resemble one another chemically just as the rare-earth elements resemble one another. He also worked on the isolation of uranium-233, which proved valuable as a nuclear fuel.

Seaborg was born at Ishpeming, Michigan. He studied at the University of California at Los Angeles and at Berkeley, where he received his doctorate in 1937 and then joined the faculty, working first as research associate, then as instructor, and later as assistant professor. During World War II he worked on the industrial production of plutonium at the University of Chicago's metallurgical laboratory. He became professor of chemistry and associate director of the radiation laboratory at Berkeley in 1945, and from 1958 to 1961 he served as chancellor of the university. In 1961 he was appointed chairman of the U.S. Atomic Energy Commission.

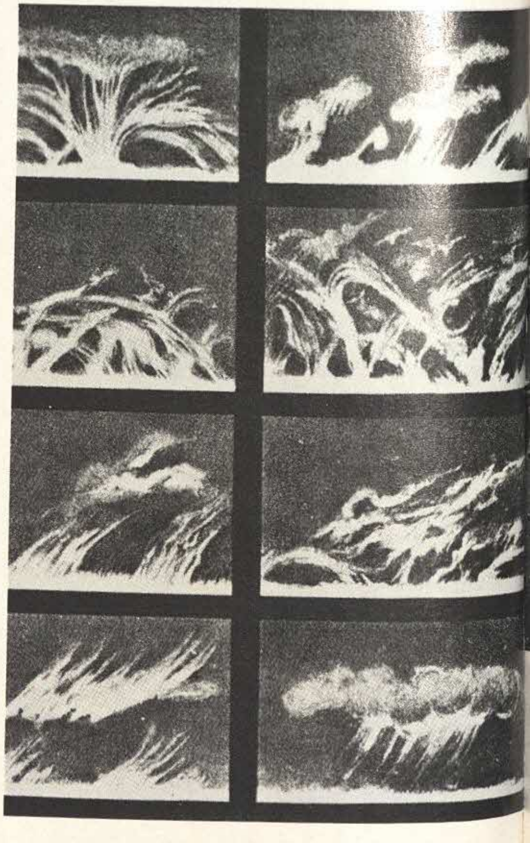
Glenn Seaborg

He became a member of the National Academy of Sciences in 1948. His published works include *Chemistry of the Actinide Elements* (1957) and *Transuranium Elements* (1958).

SECCHI, PIETRO ANGELO (1818–1878)

The Italian astronomer Pietro Secchi chose solar and stellar physics as his area of specialization. He made the first systematic spectroscopic study of the stars, dividing the stars into four spectral

Pietro Secchi's studies of solar prominences are illustrated in his book *The Sun* (1870), which show them to be of many different shapes.



groups. His system was developed into the Harvard classification, which formed the basis for all the systems of stellar classification that followed.

In his studies of astronomy Secchi used the then new technique of photography. He managed to take pictures of the 1851 solar eclipse and later made a series of photographs of the moon. He also made observations of comets, meteors, and some of the planets.

Secchi was born at Reggio, Italy, and educated by the Jesuits. In 1833 he entered the Jesuit order and subsequently held teaching positions in several Jesuit schools, including Georgetown University near Washington, D.C. After being appointed director of the observatory at the Roman College in Rome in 1849, he introduced new equipment designed for astrophysical research and carried out his spectroscopic studies. He also investigated terrestrial magnetism and meteorological phenomena. His work earned him a number of honors, including membership in the Royal Society in 1856.

SEGRÈ, EMILIO GINO (1905–)

For confirming the existence of the antiproton the Italian-born U.S. physicist Emilio Segrè was awarded the 1959 Nobel Prize in physics. He shared the prize with his co-worker Owen Chamberlain. (See Owen Chamberlain.)

The antiproton is a particle with a negative charge and with the mass of a proton. Scientists had predicted the existence of the antiproton for about twenty years before Segrè and Chamberlain proved that it does exist. In 1955, working with the powerful bevatron at the University of California at Berkeley, Segrè and Chamberlain bombarded copper atoms with high-energy protons. The two scientists were able to separate a small number of antiprotons from the large number of particles thus formed.

In his research that led to the discovery of the antiproton, Emilio Segrè (far left) was aided by a group of scientists, chief of whom was Owen Chamberlain (far right).

Emilio Segrè

Segrè also worked on the problem of artificially producing elements. In 1937 he and his colleague C. Perrier were responsible for the first man-made element, technetium (atomic number 43); at that time it was the lightest known element. Three years later Segrè was one of a group of scientists who synthesized astatine (atomic number 85); and in 1941 he was one of a group that discovered an isotope of plutonium, a substance that was used to sustain a chain reaction in the original atomic bomb.

Segrè was born in Tivoli, Italy, and in 1928 received his doctorate in physics from the University of Rome. In the 1930s he worked in Rome with the renowned physicist Enrico Fermi and in 1936 began teaching at the University of Palermo. While visiting California in 1938, he was dismissed from his post at Palermo by Italy's fascist government and decided to remain in the United States and work at the University of California at Berkeley, becoming professor of physics there in 1946. Meanwhile, from 1943 to 1946, he was a group leader at the Los Alamos Scientific Laboratory in New Mexico, engaged in research on atomic weapons. He became a naturalized citizen of the United States in 1944 and was elected to the National Academy of Sciences in 1957.

SEMENOV, NIKOLAI NIKOLAEVICH
(1896–)

The first citizen of the Soviet Union to be awarded a Nobel Prize was the Russian physical chemist Nikolai Semenov. For his work on the kinetics of chemical reactions, he shared the 1956 Nobel Prize in chemistry with Sir Cyril Hinshelwood. (*See* Sir Cyril Norman Hinshelwood.)

Semenov discovered the branched-chain reaction in the oxidation of phosphorus in 1926. He found that explosions caused by chain ignition differ from thermal explosions in not requiring preheating. In a chain involving atoms and radicals the reaction rate rapidly increases and an explosion occurs when the number of branchings exceeds the number of terminations. Like Hinshelwood, Semenov proposed that with gases the chain terminates at the wall of the receptacle. Semenov concluded that heat is the cause of thermal explosions but the product of chain explosions, and in 1928 he first stated his theory of thermal explosions, which he revised twelve years later. In 1931 he discovered a variety of branched-chain reactions called degenerate branching, useful in explaining such phenomena as the induction periods of the oxidation process. He also did important work on the propagation of explosive waves.

Semenov was born at Saratov and educated at Petrograd University (later renamed Leningrad University), graduating in 1917 during the turmoil of the Russian Revolution. From 1920 to 1931 he headed the Electronic Phenomena Laboratory of the Leningrad Physicotechnical Institute. He was also lecturer and then professor at the Leningrad Polytechnic Institute from 1928 to 1944. Meanwhile, in 1931, he also became head of the Institute of Chemical Physics of the Academy of Sciences of the Union of Soviet Socialist Republics. He was appointed professor at Moscow State University in 1944.

Many honors were conferred on Semenov by his own country and other nations. In 1932 he became a member of the Academy of Sciences of the Union of Soviet Socialist Republics and in 1941 was awarded the State Prize. He was elected a member of the Royal Society in 1958 and was similarly honored by the Hungarian Academy of Sciences in 1961, the U.S. National Academy of Sciences in 1963, and the Czechoslovakian Academy of Sciences in 1965.

SHAPLEY, HARLOW (1885–)

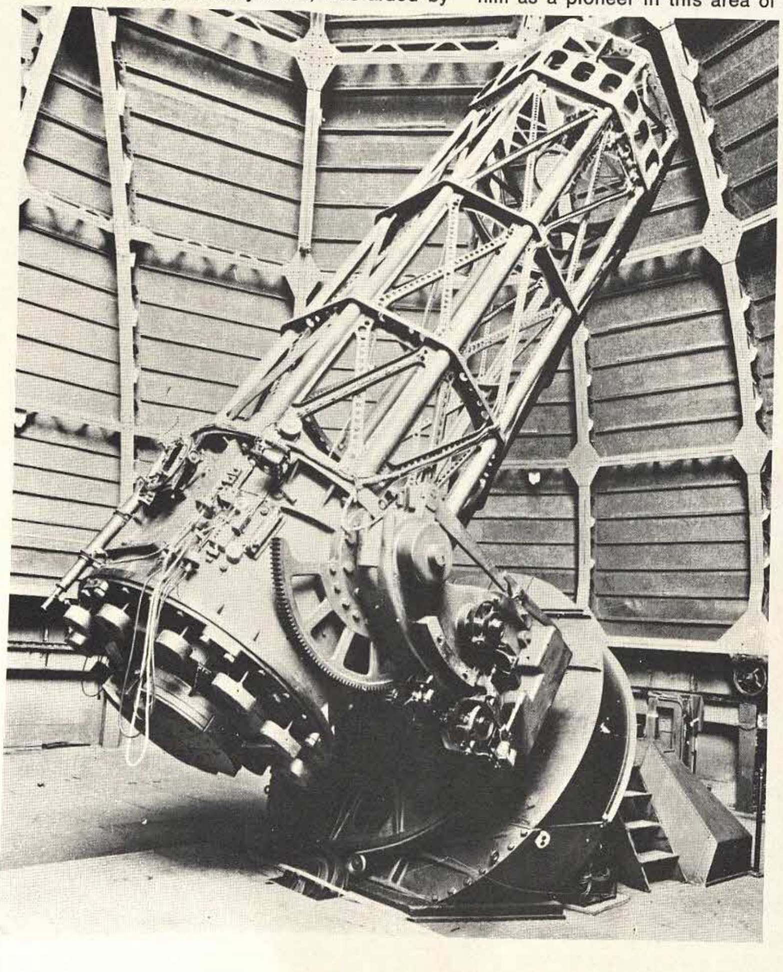
The U.S. astronomer Harlow Shapley is best known for his studies of the structure of the Milky Way and of the universe beyond it. He also developed the revolutionary hypothesis that the sun is not at the galactic center but some tens of thousands of light-years from it. In his work he was aided greatly by the use of large numbers of photographs of the sky. His efforts marked the beginning of modern galactic astronomy.

Harlow Shapley

Shapley was born at Nashville, Missouri, and received his master's degree from the state university in 1911 and his doctorate from Princeton University in 1913. The following year he became astronomer at Mount Wilson Observatory near Pasadena, California. In 1921 he was named director of the Harvard College Observatory, becoming professor emeritus of the observatory and Paine Professor of Astronomy at Harvard in 1952. Although named a professor emeritus at Harvard in 1956, he continued lecturing there and at other schools on cosmography.

Among the awards received by Shapley for his work were the Gold Medal of the Royal Astronomical Society and the Bruce Medal of the Astronomical Society of the Pacific. He was elected to the National Academy of Sciences in 1924. His books include *Galaxies* (1943), *Of Stars and Men* (1958), and *View from a Distant Star* (1963).

Harlow Shapley's observation of the skies, especially the galactic systems, was aided by powerful telescopes. His work established him as a pioneer in this area of astronomy.



SHERRINGTON, SIR CHARLES SCOTT
(1857–1952)

The British physiologist Sir Charles Sherrington received the 1932 Nobel Prize in medicine or physiology for his studies of the nervous system. He shared the prize with E. D. Adrian. (*See* Edgar Douglas Adrian.)

Much of man's fundamental knowledge of the nervous system grew from the basic work of Sherrington. He charted the motor areas of the cerebral cortex, pointing out which areas of the cortex govern motion for various parts of the body. By 1894 he produced evidence that one-third to one-half of the nerve fibers leading to the muscles are sensory; this proved that the brain is measuring stresses placed on the muscles and balancing the body accordingly. His studies of the physiology of the spinal cord after isolation from the brain showed the presence of sense organs in the skeletal muscles. He had a continuing interest in reflex behavior and in 1891 published his first paper on the knee-jerk reflex, which he later identified as a muscle stretch reflex of the spine's motor-neuron pool.

Sherrington was born in London, England. After receiving a bachelor's degree in natural science from Gonville and Caius College, Cambridge University, in 1883, he studied medicine at St. Thomas Hospital Medical School and in 1885 received his bachelor's degree in medicine from Cambridge. In 1891 he was appointed professor of pathology at the University of London, in 1895 he was named professor of physiology at the University of Liverpool, and from 1913 to his retirement in 1935 he served as professor of physiology at Oxford University. Many of the great physiologists and neurologists of the twentieth century studied or worked with him, and his influence had a far-reaching effect.

He was elected a fellow of the Royal Society in 1893, and from 1920 to 1925 served as its president. He was knighted in 1922.

SHIBASABURŌ. See Kitasato, Baron Shibasaburō.

SHIN'ICHERO. See Tomonaga, Shin'ichero.

SHOCKLEY, WILLIAM BRADFORD
(1910–)

One of the men whose research led to the development of transistors and transistor technology was the U.S. physicist William Shockley. For his part in the invention of the transistor, he shared the 1956 Nobel Prize in physics with John Bardeen and Walter Brattain. (*See* John Bardeen; Walter Houser Brattain.)

In 1946, while employed at the Bell Telephone Laboratories, Shockley, Bardeen, and Brattain began doing research on semiconductors, such as germanium and silicon. At the time, it was known that these semiconductors acted as rectifiers, and Shockley found that their conductivity was dependent upon certain impurities. Semiconductors were of two types, having either negative conductivity or positive conductivity, depending upon the types of impurities that were present. Shockley also found that these

While at the Bell Telephone Laboratories, William Shockley (seated), with John Bardeen and Walter Brattain, invented the transistor.

solid-state rectifiers were more efficient than tubes in the operation of radios and other electronic equipment. He combined the positive and negative types in such a way that they amplified as well as rectified an electric current. This led to the development of the point-contact transistor and later the junction transistor. He wrote a book on this work, *Electrons and Holes in Semiconductors* (1950).

Shockley was born in London, England, to parents who were U.S. citizens. He was raised in California and educated at the California Institute of Technology, Pasadena. After receiving his doctorate from the Massachusetts Institute of Technology, Cambridge, in 1936, he went to work for the Bell Telephone Laboratories. During World War II he served as director of research for the U.S. Navy's Antisubmarine Warfare Group and as a consultant to the secretary of war. On his return to the Bell laboratories after the war, he became director of transistor-physics research. From 1954 to 1955 he was deputy director of the Weapons Systems Evaluation Group of the U.S. Department of Defense, in 1955 he became head of the Shockley Semiconductor Laboratory at Beckman Instruments, Inc., and in 1963 he was appointed professor of engineering science at Stanford University, Palo Alto, California. He was elected to the National Academy of Sciences in 1951.

SIEGBAHN, KARL MANNE GEORG (1886–)

The Swedish physicist Manne Siegbahn was awarded the 1924 Nobel Prize in physics for his discoveries and research in the field of x-ray spectroscopy. His early research was devoted mainly to electricity and magnetism, but after 1914 he began systematic investigations of the x-ray spectra of elements. In 1916 he discovered the long-wave M-lines, a new spectral series; and in 1924 he and his colleagues proved that x-rays diffract in prisms.

Siegbahn was born in Örebro, Sweden, and educated at the University of Lund, where, after receiving his master's and doctorate, he was lecturer in physics from 1911 to 1920 and professor of physics from 1920 to 1923. The following year he became professor of physics at the University of Uppsala and stayed there until 1937, when he was appointed director of the newly created Nobel Institute of Experimental Physics of the Swedish Royal Academy of Sciences, Stockholm. He remained in that post until 1964.

He was awarded the Hughes Medal of the Royal Society of London in 1934 and its Rumford Medal in 1940, as well as the Duddel Medal of the Physical Society of London in 1948. In the 1960s he was named an honorary member of the International Committee on Weights and Measures after serving on that body for more than twenty-five years.

SIKORSKY, IGOR IVAN (1889–)

The Russian-U.S. aviation engineer Igor Sikorsky designed the world's first multiengine airplane. He also developed the first practical helicopter, as well as the Sikorsky multimotored amphibian.

He was born in Kiev, Russia, and educated in Russia and France. At an early age he became interested in aviation and aeronautics and studied under Louis Blériot and Ferdinand von Zeppelin. In 1909 he constructed an experimental helicopter and then turned his attention to multiengine craft. He built the first four-engine airplane, which he named *The Grand,* completely outfitted with a passenger cabin, and a larger, more sophisticated plane that was redesigned for military use and proved successful as a bomber in World War I. These planes are considered the forerunners of modern commercial and military craft.

Following the Russian Revolution, Sikorsky went to England and France for short periods and then emigrated to the United States. In 1923 he formed the Sikorsky Aero Engineering Corporation on a farm on Long Island, New York, where he developed a number of airplanes, including an amphibian craft that he sold to Pan American Airways for service to Central and South America. Sikorsky's company became a division of the United Aircraft Corporation in 1929 and began building passenger flying boats, including one capable of transatlantic flight. This opened up commercial air transportation across the Atlantic and Pacific oceans.

Sikorsky had always been interested in creating a direct-lift aircraft, and in 1939 he built his first practical model, the VS-300. After perfecting the design, he began manufacturing the helicopters for military use; and advanced models of the craft were soon put to commercial use. In the 1950s Sikorsky began utilizing turbine engines in his helicopters, and their place in aviation became firmly established. The pioneer aviator retired in 1957 from United Aircraft.

A biography, *The Story of the Winged S,* was published in 1938. Sikorsky became a naturalized U.S. citizen in 1928.

SIMPSON, GEORGE GAYLORD (1902–)

The U.S. geologist and paleontologist George Simpson is best known for his studies on the evolution of mammals. In the 1920s and 1930s he concentrated on studying fossil mammals of the Paleocene and Eocene epochs in North and South America, and in the 1940s and 1950s he collected Eocene fossils of the San Juan Basin in New Mexico. Aided by his wife, psychologist Anne Roe, he also did extensive behavioral studies.

Although born in Chicago, Illinois, Simpson spent his early life in Colorado. As a graduate student at Yale University, he did extensive research on early mammals both in the United States and abroad. After receiving his doctorate in 1926, he joined the staff of the American Museum of Natural History in New York City, where he became curator of fossil mammals and chairman of geology and paleontology. In 1945 he was appointed professor of zoology at Columbia University and stayed there until 1959, when he went to Harvard as professor of paleontology.

Simpson was elected to the National Academy of Sciences in 1941 and to the American Academy of Arts and Sciences in 1948. His essay on the history of vertebrate paleontology won the Lewis Prize of the American Philosophical Society in 1942, and in 1945 he published a classification of all known mammals, with data on their time and place. Other works by Simpson include *Attending Marvels: A Patagonian Journal* (1934), *Quantitative Zoology* (with Anne Roe; 1939), *The Major Features of Evolution* (1953), *Principles of Animal Taxonomy* (1961), and *The Geography of Evolution* (1965).

SLIPHER, VESTO MELVIN (1875–)

The first observational evidence to support the theory of the expanding universe was provided by the U.S. astronomer Vesto Slipher, who discovered the rapid motion and extraordinary space velocities of the spiral nebulas. He also directed the research that led to Clyde Tombaugh's discovery of the planet Pluto, the existence of which had been predicted by another U.S. astronomer, Percival Lowell.

His spectroscopic studies led to the identification of the gases that make up the atmospheres of the planets, particularly Jupiter and Saturn, and in 1933 he found that the atmosphere of Neptune contains methane. He also made the final determination of the rotation period of Uranus.

Knowing that recessive motions are made evident by a shifting toward the red end of the spectrum, he found that all but two of the nebulas are rapidly moving away from the Earth. In this same area of study he found that the Andromeda nebula is approaching the Earth at a speed of 125 miles per second. He also demonstrated that some nebulas shine because of reflected light from other stars and determined that the elements sodium and calcium are scattered throughout interstellar space.

Slipher was born on a farm at Mulberry, Indiana, and educated at the state university. In 1901, eight years before receiving his doctorate, he began his long association with the Lowell Observatory near Flagstaff, Arizona. Eventually he became its director, and under his guidance the research that led to the discovery of Pluto was carried out.

SODDY, FREDERICK (1877–1956)

In 1913 Frederick Soddy, a British chemist, suggested that certain elements produced through radioactive transformations could be chemically identical yet have different weights. Discovery of these elements, called isotopes, earned Soddy the 1921 Nobel Prize in chemistry. Further experimentation led him to the conclusion that isotopes are actually different versions of the same chemical element, varying in the mass of the atom but not in chemical properties.

Soddy was born in Eastbourne, England. After graduating with honors in chemistry from Oxford in 1898, he went to Canada to work with Sir Ernest Rutherford at McGill University in Montreal. Together they formulated the theory that "radioactivity is at once an atomic phenomenon and the accompaniment of a chemical change in which new kinds of matter are produced." Four years later he joined Sir William Ramsay at London's University College, where they performed a classic experiment in which the gaseous product of radioactive decayed radium was identified with helium. In 1904 he went to the University of Glasgow as a lecturer in physical chemistry and remained there for ten years. It was during this period that he revealed his findings about isotopes in a letter published in *Nature* in 1913. The name Soddy chose for the elements he discovered is derived from Greek words meaning "same place," a reference to their identical location in the periodic table of elements. A year after his revelation about isotopes, Soddy left Glasgow for Aberdeen, where he taught chemistry at the university there until 1918. The following year he accepted a position as Doctor Lees Professor of Chemistry at Oxford and remained there until his retirement in 1936.

Despite his remarkable success as a scientist, Soddy seemed to lose interest in this field as he grew older. He became almost obsessed with politics and economics; between his retirement and his death twenty years later, he devoted himself to writing angry polemics on a number of controversial political and economic theories.

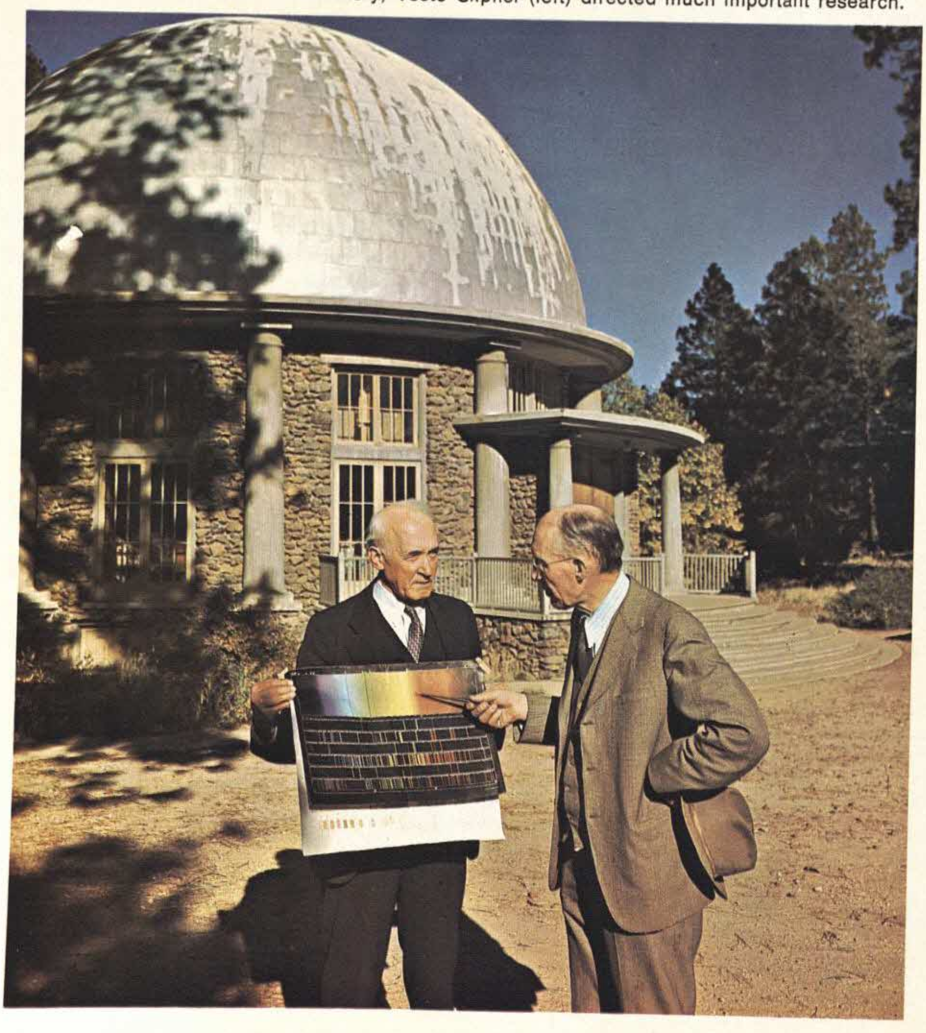
Soddy's achievements in the field of chemistry were acknowledged by the Royal Society in 1910 when he was elected a fellow. Although both this honor and the Nobel Prize were granted him at a relatively early age, Soddy later complained bitterly that his contributions were not properly appreciated.

SPALLANZANI, LAZZARO (1729–1799)

The Italian naturalist Lazzaro Spallanzani was one of the most careful and thorough experimenters in the history of biological science and is, in fact, considered to be one of the founders of experimental biology. He conducted important experiments on digestion, sexual reproduction, and respiration and disproved the theory of the spontaneous generation of microorganisms.

Some of Spallanzani's most important

As head of the Lowell Observatory, Vesto Slipher (left) directed much important research.



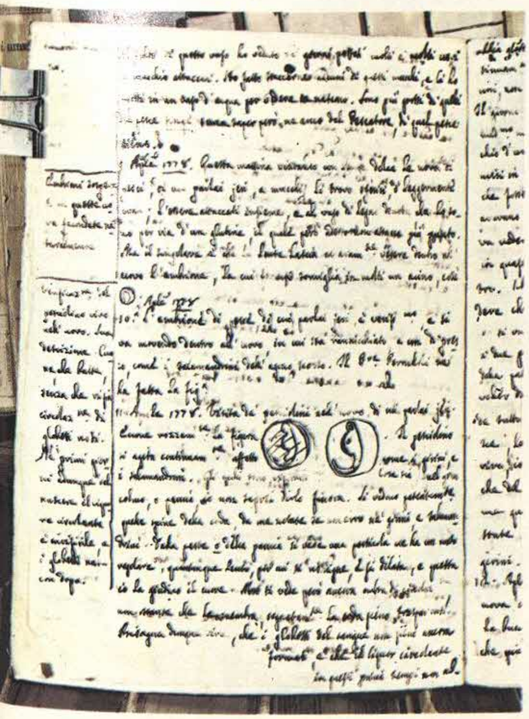
Lazzaro Spallanzani

work involved disproving the theory of spontaneous generation. He demonstrated that boiling a liquid in hermetically sealed containers made it impossible for microorganisms to develop in it. Some scientists, however, clung to their belief in spontaneous generation, claiming that Spallanzani destroyed a vital substance in the air and not microorganisms by his method of prolonged heating. It remained for Louis Pasteur to completely discredit the idea of spontaneous generation.

In his work on digestion Spallanzani found that the solvent action of the gastric juices on food in the stomach was not a form of putrefaction. He suspected that it was a form of acid fermentation, but with the methods available to him he was unable to find the acids responsible for the process.

Through his experiments on respiration he discovered that tissues take in oxygen and give off carbon dioxide. By filtering semen, he found that sperms are the ingredient responsible for fertilization, and he succeeded in artificially inseminating a female dog. Spallanzani also investigated sense perception in bats and the regeneration of appendages in certain amphibians, such as salamanders.

In one of his works, Lazzaro Spallanzani dealt with artificial insemination of animals. He was among the first to engage in such studies.



Spallanzani was born at Scandiano in the province of Modena, Italy, and educated at the University of Bologna. Although he began studying law, he later decided to make his career in the sciences, reportedly under the influence of his cousin, who was professor of physics at Bologna and one of the few women professors of that time. In 1757, after entering the priesthood, he was appointed professor of mathematics and physics at the University of Reggio; in 1763 he became professor of physics and philosophy at the University of Modena; and in 1769 he was appointed professor of natural history at the University of Pavia, where he remained for the rest of his life with the exception of the time he spent in the Mediterranean area gathering specimens for the museum at Pavia.

SPEMANN, HANS (1869–1941)

In the 1920s Hans Spemann, a German zoologist, undertook a series of experiments to demonstrate characteristics of embryonic development previously unknown. His eventual discovery of the "organizer effect" of embryonic cells upon one another resulted in his winning the 1935 Nobel Prize in medicine or physiology.

Spemann suggested that the completely formed areas surrounding a developing portion of an embryo determine the final form of the incomplete portion; for example, when a portion of tissue that would ordinarily become epidermis is transplanted near the spinal cord, it becomes nervous tissue instead. The environment in which the tissue grows is responsible for this change. The term organizer effect refers to the role played by the existent portion of the embryo on the portion that is still malleable or plastic.

Until the 1880s embryologists believed that when a fertilized ovum divided in two, its plane of bilateral symmetry was established; thus, should half of the original ovum be killed, the remaining half would presumably develop as only a half embryo. Wilhelm Roux and Hans Driesch later demonstrated that if the ovum divisions are not killed but simply separated, each one will develop into a complete but smaller embryo. If the destroyed cell remains in close proximity to the living cell, the latter will develop as only a half embryo. It was Spemann who discovered that the destroyed cell, which constitutes the environment of the living cell, has an organizing effect on that cell still in the process of forming. His findings emphasized the role played by hormones in influencing the final form embryonic structures take. Previously, it was believed some mysterious vital force predetermined all embryonic development. Spemann is credited with finally debunking the erroneous theory of preformation, according to which the fate of all ova was determined at the moment of fertilization and could not be altered.

Spemann was born in Stuttgart, Württemberg, Germany. Although he was originally interested in medicine and had studied for his degree in this field at Heidelberg and Munich, he later chose a career in zoology. In 1895 he took a degree from the University of Würzburg, where he became a lecturer in zoology three years later. He remained at Würzburg until 1908, when he assumed the chair of zoology at Rostock. Five years later he was named associate director of the Kaiser Wilhelm Institute of Biology at Berlin-Dahlem. His final teaching position was at the University of Freiburg im Breisgau; it was during his sixteen years there, from 1919 to 1935, that Spemann advanced the organizer effect theory.

STANLEY, WENDELL MEREDITH (1904–   )

The U.S. biochemist Wendell Stanley won a share of the 1946 Nobel Prize in chemistry for isolating and crystallizing the tobacco mosaic virus and showing that a virus is a protein. He divided one-half of the award with J. H. Northrop, and J. B. Sumner was awarded the other half for his discovery that enzymes are crystallizable proteins. (*See* John Hancock Northrop; James Batcheller Sumner.)

In his prizewinning research Stanley prepared a large quantity of tobacco mosaic virus by growing tobacco and infecting it. He mashed up the infected leaves and then, because he was quite certain that the virus was a protein molecule, put the mash through the usual procedures used for crystallizing proteins. In 1935 he obtained crystals, which he found to have all the infective properties of the virus in high concentration; in 1936 he isolated nucleic acid from the crystalline material; and by 1937 it had been demonstrated that the nucleic acid was responsible for the virus activity and that the tobacco mosaic virus was, therefore, a nucleoprotein. Subsequently, Stanley studied the amino acid composition of the protein and the properties of solutions of the virus nucleoprotein. During World War II he worked on the influenza virus and on preparations against the disease, developing the centrifuge-type influenza vaccine.

Stanley was born in Ridgeville, Indiana, and did his undergraduate work at Earlham College, Richmond, Indiana, receiving his bachelor's degree in 1926. After earning his doctorate at the University of Illinois, Urbana, in 1929, he stayed there a year as a research associate and a lecturer and then left for further study as a National Research Council fellow at the University of Munich, Germany. In 1931 he returned to the United States to become an assistant at the Rockefeller Institute for Medical Research (now Rockefeller University) in New York City. He transferred to its Princeton, New Jersey, facility in 1932, becoming an associate in 1935, an associate member in 1937, and a member of the institute in 1940. Eight years later he accepted the post of professor of biochemistry and director of the virus laboratory at the University of California, Berkeley, where he served as chairman of the Department of Biochemistry from 1948 to 1954 and was appointed professor of virology and chairman of the virology department in 1958. He was elected to the National Academy of Sciences in 1941.

STARK, JOHANNES (1874–1957)

For his discovery that spectral lines are distorted in an electric field the German physicist Johannes Stark received the 1919 Nobel Prize in physics. By using a third electrode near the perforated cathode in a discharge tube, he was able to apply a strong electric field and thus observe multiple splitting of the lines. This phenomenon is now known as the Stark effect.

Stark's interest in the mechanics of the discharge tube was typical of many German physicists in the early 1900s. In his work *Electricity in Gases,* published in 1902, Stark suggested that the high-velocity rays in a discharge tube exhibit the Doppler effect, an apparent change in radiation frequency emitted by a moving body. He proved this three years later by demonstrating that the lines of the hydrogen spectrum moved slightly to the violet or red ends of the spectrum depending on whether the rays were approaching or receding from the observer. For this explanation of the Doppler effect in parallel rays he was awarded the 1909 Baumgartner Prize by the Vienna Academy.

The modern theory of radiation and the atomic theory were Stark's particular interests. In addition to his discovery of the effect bearing his name, he is credited with significant findings about the effect of light on chemical reactions.

Stark, a native of Schickenhof, Bavaria, took a degree in physical science from the University of Munich in 1898 and remained there until 1900, working at the school's Physical Institute. His teaching career began later that year when he became an assistant professor at the University of Göttingen. From 1906 until his retirement in 1922, he was full professor of physics at four schools successively: the technical colleges of Aachen and Hanover and the universities of Greifswald and Würzburg. During much of this period he edited the *Yearbook of Radioactivity and Electronics,* a publication he founded in 1904. Stark's term as the president of the Reich Physical-Technical Institute, Charlottenburg, lasted from 1933 to 1939. The anti-Semitic racial theories of Adolf Hitler appealed to Stark, and he wrote a book on nazism. Although his sentiments stabilized his position at the Reich Institute, it also earned him four years in a labor camp at the end of World War II.

STAUDINGER, HERMANN (1881–1965)

German chemist Hermann Staudinger received the 1953 Nobel Prize in chemistry for his work on macromolecules (high-molecular compounds). His theory explaining the phenomenon of polymerization made possible many of the processes used in the wide-scale manufacture of plastics and other high-polymer synthetics.

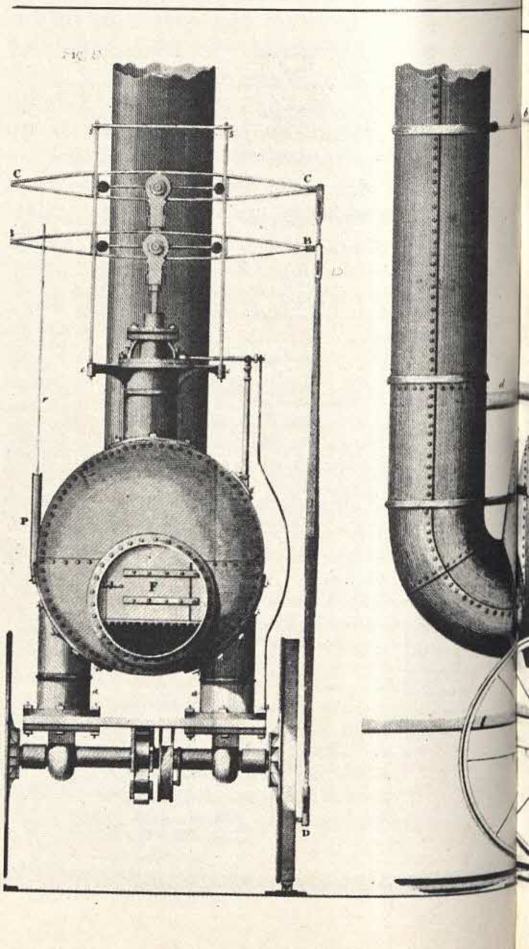
Staudinger became interested in macromolecules after the discovery of the first all-synthetic plastic in 1906. The composition of low-molecular compounds had been established in the nineteenth century, but no one had successfully explained the structure of high-molecular compounds. Staudinger showed that molecules polymerize by chemical interaction, not by simple physical aggregation. He also established the relationship between the molecular weight of a high polymer and its viscosity in solution. He worked widely with rubber, styrene, and cellulose as well as synthetic polymers. In addition to research with high-molecular compounds, Staudinger discovered several important low-molecular synthetic compounds that had wide commercial applications.

Staudinger was born in Worms, Germany, and was educated at the German universities of Munich, Darmstadt, and Halle, where he obtained his doctorate in organic chemistry in 1903. He became a lecturer while continuing his studies at the University of Strasbourg in 1907 but left the same year to become assistant professor of organic chemistry at the Chemical Institute of the Technical College of Karlsruhe. In 1912 he was made professor of general chemistry at the Federal Institute of Technology, Zürich, Switzerland, where he remained until 1926. In that year he went to the University of Freiberg, Germany, where he first held a chair of chemistry, then became general director of the Chemical Laboratory and Research Institute for Macromolecular Chemistry, and finally was made professor emeritus. He left the institute in 1956 to devote his time to writing his memoirs.

STEPHENSON, GEORGE (1781–1848) **and ROBERT** (1803–1859)

Two of the men who contributed most to the development of railways were the English inventors and engineers George and Robert Stephenson. The elder Stephenson is considered to be the founder of railways and the inventor of the steam locomotive (even though other inventors came up with similar engines at approximately the same time). Robert, his son, aided him with the design of certain locomotives and in his own right was a famous designer of tubular railway bridges.

George Stephenson was born at Wy-



lam near Newcastle-on-Tyne, the son of a poor mine worker. He had no formal education and at age fourteen began assisting his father in operating a water-pumping engine at a colliery. In 1804, after operating similar machinery at various coal mines, he took a job at the Killingworth colliery. His wife and a daughter died shortly thereafter, and accepting the job at Killingworth proved to be a turning point in his life.

He devoted himself to raising his only son, Robert, with whom he became very close, and also to learning about the machinery involved in his job. So that he might read the works of James Watt he took a reading course at a night school. By 1812 he was placed in charge of all the machinery at the Killingworth colliery.

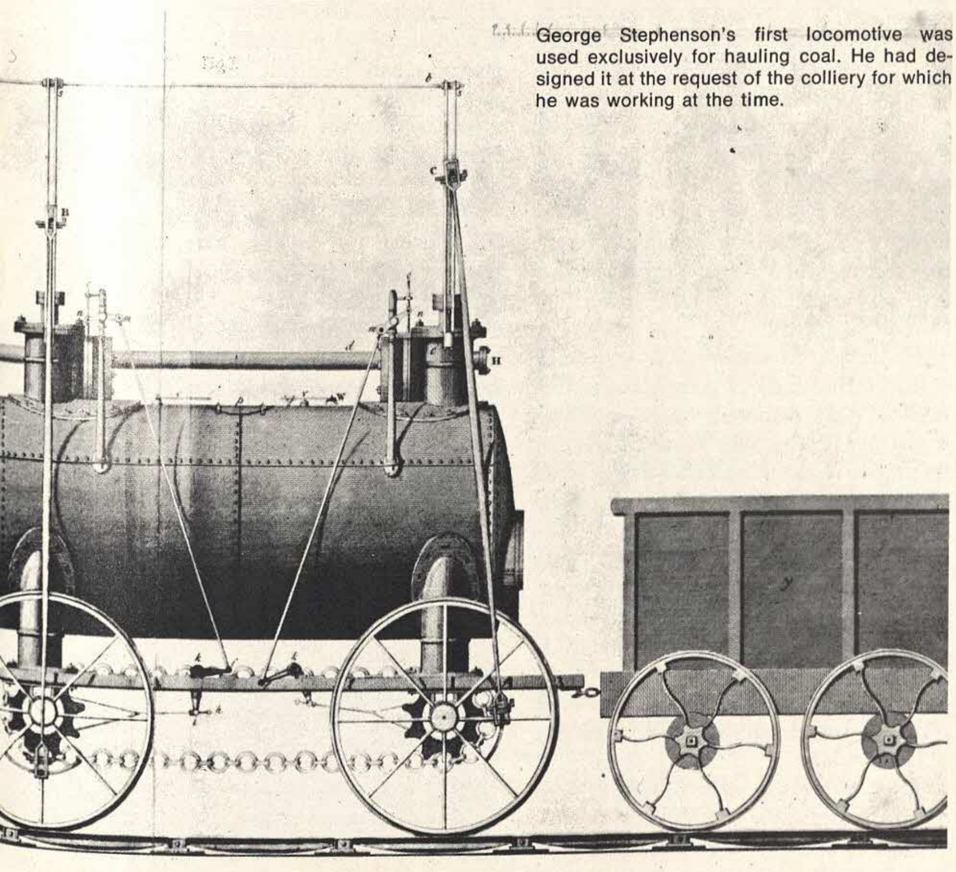
Next, the colliery asked him to build a locomotive for hauling coal. His first engine, the *Blucher*, with flanged wheels, made its first run in 1814. At about the same time, he devised a safety lamp for miners, but this invention was similar to one developed by Sir Humphry Davy, and a controversy developed over priority to the invention.

In 1815 he patented his steam-blast locomotive. Then from 1819 to 1822 he worked on an eight-mile railway for the Ti[illegible]son colliery. In 1823 he helped found Robert Stephenson and Company, a locomotive works at Newcastle-on-Tyne. In 1825 his locomotive the *Active* (later renamed the *Locomotion*) pulled the world's first public passenger train on the Stockton and Darlington Railway. His prizewinning engine the *Rocket* achieved speeds up to thirty miles per hour in 1829. In 1830 an eight-engine train that he built established the world's first mainline passenger service on the Liverpool-Manchester Railway. He also helped develop railroad systems on the Continent.

The younger Stephenson, a mechanical and civil engineer, was born at Willington Quay near Newcastle-on-Tyne. He was more fortunate than his father in obtaining a formal education and was able to spend one year at Edinburgh University. He also served, however, an apprenticeship at the Killingworth colliery. In 1824 he went to work for a mining company in South America but returned to England in 1827 to help his father at the Newcastle locomotive works. He aided in the design of some of his father's early locomotives but also built locomotives of his own and made many improvements in existing designs.

His special province, however, was building tubular-girder railway bridges. His first bridge was a failure, for it collapsed when a train passed over it, but his subsequent attempts were spectacular successes. He built the Britannia Bridge over the Menai Straits (with a 459-foot span), the High Level Bridge over the Tyne at Newcastle, a bridge over the Conway, and the Victoria Bridge over the St. Lawrence River at Montreal, Quebec.

Robert also engaged in politics and served as a member of Parliament from 1847 until his death. In 1849 he was elected a fellow of the Royal Society. He was further honored after his death with burial in Westminster Abbey.


George Stephenson's first locomotive was used exclusively for hauling coal. He had designed it at the request of the colliery for which he was working at the time.

STERN, OTTO (1888–)

The German-U.S. chemist Otto Stern measured the magnetic moment of the proton (the strength of its magnetic property) and for the achievement was awarded the 1943 Nobel Prize in physics.

Stern's major scientific contribution was in the field of theoretical physics, especially statistical thermodynamics. Beginning at Frankfurt am Main, Germany, in the 1920s, he developed the molecular-beam method of investigating atoms, molecules, and atomic nuclei. Working with a beam of silver atoms, he found a method to prove directly the existence of an atomic magnetic moment and measured its magnitude. This method also provided the first evidence of spatial quantization (expressed in terms of the quantum theory). While at Hamburg in the early 1930s, he was able to measure the magnetic moment of the proton and found the value to be more than twice as great as had been theorized.

Stern was born in Sorau, Germany (now Poland), and received his education at the University of Breslau, where he earned his doctorate in physical chemistry in 1912. He joined scientist Albert Einstein at the University of Prague, Czechoslovakia, and then followed him to Zürich, Switzerland, where Stern became a lecturer of physical chemistry at a high school. In 1914 he was made a lecturer of theoretical physics at the University of Frankfurt am Main, Germany, where he remained until 1921, except for a brief period of military service during World War I. Stern then spent a year as associate professor of theoretical physics at Rostock before being appointed professor of physical chemistry at the University of Hamburg in 1923. He remained at that post until he was forced to leave Germany in 1933, when he went to the United States and became a research professor of physics at the Carnegie Institute of Technology in Pittsburgh, Pennsylvania. In 1945 Stern retired and moved to Berkeley, California, and was elected to the National Academy of Sciences.

STRADONITZ. See Kekulé von Stradonitz, Friedrich August.

SUMNER, JAMES BATCHELLER (1887–1955)

The U.S. scientist James Batcheller Sumner, whose early loss of an arm did not deter him from a career in biochemistry, won half of the 1946 Nobel Prize in chemistry. He was the first to isolate an enzyme in pure crystalline form and to show beyond doubt that enzymes are proteins. Dividing the other half of the prize were J. H. Northrop and W. M. Stanley. (*See* John Howard Northrop; Wendell Meredith Stanley.)

Sumner, the son of a farmer and cotton manufacturer, was born in Canton, Massachusetts. At age seventeen, Sumner, who was left handed, lost his left arm in a hunting accident. Six years later he received his bachelor's degree in chemistry from Harvard University, Cambridge, Massachusetts, and began his teaching career at Mount Allison College, Sackville, New Brunswick, Canada. In 1911 he became an assistant in chemistry at the Worcester Polytechnic Institute in Massachusetts but left in 1912 to study biochemistry at Harvard's Medical School. After earning his master's degree in 1914 and his doctorate in 1915, Sumner went to Cornell University's Medical College, New York City, as assistant professor of biochemistry. In 1929 he was made professor, a post he held until his retirement; and, in addition, in 1947 he became director of the Cornell Laboratory of Enzyme Chemistry, established by the university trustees in recognition of his investigations.

Sumner's early work included the study of urea formation. In 1926 he isolated urease, an enzyme that catalyzes the breakdown of urea to ammonia and carbon dioxide. His further research showed that the crystals he had obtained were protein.

Although Sumner's accomplishment confirmed the views of a few biochemists, his work did not at once gain wide acceptance. The immediate result of his effort was the spurring of research in the related fields of viruses and viral diseases. The view that enzymes are proteinaceous steadily gained followers, however, and Sumner's work was fully appreciated when Northrop, in the early 1930s, extended it to the crystallization of other enzymes. In 1937 Sumner crystallized the enzyme catalase, which influences reactions involving hydrogen peroxide and protects the living cells from this compound, which they produce during the respiratory process.

During the years that he was connected with Cornell University, Sumner did enzyme research for a time in Sweden—with Hans von Euler-Chelpin at the University of Stockholm and with Theodor Svedberg at the University of Uppsala. Sumner was awarded the Scheele Medal at Stockholm in 1937.

He published *Biological Chemistry* in 1927 and was coauthor of three editions of two books: *Chemistry and Methods of Enzymes* and *Laboratory Experiments in Biological Chemistry.* With Karl Myrbäck, he compiled four volumes of *The Enzymes: Chemistry and Mechanism of Action* (1950–1952).

SVEDBERG, THEODOR (1884–   )

An interest in colloids dating from his student years at the University of Uppsala spurred Theodor Svedberg on to win the Nobel Prize in chemistry in 1926. His early experiments were concerned with preparing metal colloidal suspensions by setting up electric arcs between metal electrodes submerged under water. Later he invented a tool for studying these suspensions.

Prior to Theodor Svedberg's discoveries, chemists were unable to determine much about the size and shape of colloidal particles or their rate of settling. An insurmountable problem seemed to be the jarring effect of water molecules that prevented the particles from settling out. It appeared that only increased gravitational pull would deter these molecular collisions and thereby permit the settling out of the particles. Utilizing the centrifugal effect by which milk was separated from cream, and blood corpuscles from plasma, Svedberg developed the ultracentrifuge, a whirling device capable of producing an effect 100,000 times that of normal gravity.

Svedberg's invention was especially useful in the study of protein molecules. Because this extremely large molecule is, by itself, the size of a colloid, its properties remain colloidal even when it has gone into solution. Thanks to ultracentrifuge, individual protein molecules could be effectively settled out and their weights determined for the first time. Most valuable was Svedberg's revelation that the molecules of certain proteins are the same size; by isolating these molecules, chemists could finally identify extraneous contaminating material in proteins.

After inventing the ultracentrifuge, Theodor Svedberg continued to explore protein structure, with emphasis on the field of high polymers. He successfully elucidated the properties of many long chain molecules, the most important of which was cellulose. He also advanced the study of electrophoresis, another technique for observing protein composition.

Svedberg was born in Fleräng, Sweden, and educated at Uppsala, where he spent much of his professional career. From 1912 until 1949, when he became professor emeritus, he taught physical chemistry. In addition to teaching and conducting research, Svedberg served as director of the Institute of Physical Chemistry during his last eighteen years at Uppsala. In 1949 he was appointed director of the Gustaf-Werner Institute.

SYNGE, RICHARD LAURENCE MILLINGTON (1914–   )

The British biochemist Richard L. M. Synge is best known for his part in the development of partition, or paper, chromatography. He worked on this project with Archer J. P. Martin, sharing the 1952 Nobel Prize in chemistry with him. (*See* Archer John Porter Martin.)

Synge was born at Liverpool, England. He received his education at Winchester College and at Trinity College, Cambridge, obtaining his doctorate in 1941. His association with Martin began at Cambridge, when Synge was working on the separation of acetylated amino acids. Together they developed the technique of partition chromatography, which proved to be an invaluable tool in biochemical and medical research. Synge used partition chromatography to discover the structure of a relatively simple protein molecule, the antibiotic gramicidin-S.

From 1941 to 1943 Synge worked at the Wool Industries Research Association at Leeds, where he kept up his collaboration with Martin. Then in 1943 he joined the staff of the Lister Institute of Preventive Medicine in London. After 1945 Synge devoted himself to analytical problems involving amino acids and peptides. He studied the digestion of proteins in ruminant animals and also physicochemical methods of identifying and purifying intermediates in the protein metabolism of plants.

In 1948 Synge was appointed head of the protein-chemistry department at the Rowett Research Institute at Bucksburn, Aberdeenshire, Scotland. Two years later he was elected to the Royal Society.

SZENT-GYÖRGYI, ALBERT (1893–   )

Biochemist Albert Szent-Györgyi was awarded the 1937 Nobel Prize in medicine or physiology for his discoveries

Albert Szent-Györgyi

concerning biological combustion and the isolation of ascorbic acid. Szent-Györgyi's most important scientific work involved the isolation of ascorbic acid from adrenal glands and plant tissues. He proved that the substance was identical to vitamin C, and he also demonstrated the presence of flavin in animal tissues.

Szent-Györgyi was born in Budapest, Hungary, and attended the University of Budapest, where he received his medical degree in 1917, and various other European schools, studying pharmacology, chemistry, and biochemistry. He received a doctorate in chemistry at Cambridge University, England, in 1927.

Szent-Györgyi spent a year in the United States at the Mayo Clinic in Rochester, Minnesota. He returned to Hungary in 1932 but emigrated to the United States following World War II and became associated with the Marine Biological Laboratory in Woods Hole, Massachusetts, where he headed the Institute for Muscle Research.

He was elected to the National Academy of Sciences in 1956 and the American Academy of Sciences in 1957. He wrote more than 200 scientific papers and several books, including *On Oxidation, Fermentation, Vitamins, Health, and Disease* (1940), *Chemistry of Muscular Contraction* (1947), *Nature of Life: A Study on Muscle* (1948), *Chemical Physiology of Contraction in Body and Heart Muscle* (1948), *Bioenergetics* (1957), and *Introduction to a Submolecular Biology* (1960).

After World War II, Albert Szent-Györgyi conducted experiments at the Marine Biological Laboratory in Woods Hole, Massachusetts.

TAMM, IGOR EVGENYEVICH (1895–1971)

The well-known Soviet physicist Igor Evgenyevich Tamm made contributions to the peaceful use of atomic power and in the 1960s made an international plea for disarmament. Tamm's achievements in the field of nuclear physics were many and varied. He received the 1958 Nobel Prize in physics for his work in interpreting Cherenkov radiation. The prize was shared with Pavel Alekseevich Cherenkov and Ilya Mikhailovich Frank, fellow Soviet physicists. Cherenkov discovered the radiation that bears his name in 1934, and Tamm and Frank provided the theoretical interpretation for it in 1937. (*See* Pavel Alekseevich Cherenkov; Ilya Mikhailovich Frank.)

Cherenkov radiation is emitted by high-energy electrons moving through a medium, usually liquid, at a very high speed. Tamm and Frank provided a detailed mathematical explanation of how the radiation originates and of its characteristics. An unusual feature of Cherenkov radiation is that the light waves are produced in uniform motion; previously, radiation had been produced only through irregular motions, such as oscillation.

Tamm also worked on ways to control thermonuclear reactions. He devised a method, now known as the Tamm method, for studying the relationships among elementary nuclear particles.

Tamm was born in Vladivostok, the son of an engineer. He was graduated in physics from Moscow State University in 1918. In 1933 he received a doctorate in physical-mathematical sciences.

Beginning in 1919 he taught at several universities. In 1924 he became an instructor at Moscow State; he was promoted to professor relatively quickly, in 1927. He held the chair of theoretical physics from 1930 to 1941. In 1934 he also was made head of the Lebedev Institute of Physics of the Academy of Sciences of the U.S.S.R. For their discoveries concerning electron radiation, Cherenkov, Frank, and Tamm were awarded the Stalin Prize in 1946.

TARTAGLIA, NICCOLO (1499–1559)

The Italian mathematician Niccolo Tartaglia was the founder of the science of ballistics. He also claimed to have discovered the solution to the cubic equation. He confided his discovery to J. Cardan, who made certain improvements and then published the solution as his own. This led to a long public controversy over who should be credited with solving the equation.

Niccolo Tartaglia

He was born Niccolo Tartalea in Brescia, Italy, and because the family was extremely poor he was self-educated. In 1512, when the French invaded Brescia, he suffered saber cuts on his head, which resulted in a speech impediment that led to his adoption of the name Tartaglia, meaning "the stutterer."

From 1521 to 1534 he taught mathematics at Verona. In 1534 he went to Venice, and in 1548 he went back to Brescia to teach geometry. He soon returned to Venice, however, and lived there for the remainder of his life.

Tartaglia's first publication, *Nova Scientia* (1537), dealt with problems of gunnery and represented one of the first attempts to establish the laws of falling bodies and to apply mathematics to gunnery. Tartaglia claimed credit for inventing the gunner's quadrant.

He also wrote works on such topics as the diving bell and the raising of sunken ships. His *Trattata Generale* (1556), the best collection of mathematical methods of the time, contained an important section on statistics. He published the first Italian translation of Euclid and the first Latin edition of Archimedes.

TATUM, EDWARD LAWRIE (1909–)

The 1958 Nobel Prize in medicine or physiology was shared by Edward Lawrie Tatum, George Wells Beadle, and Joshua Lederberg for their work in genetics. Tatum, a biochemist, worked first with Beadle and then with Lederberg. (*See* George Wells Beadle; Joshua Lederberg.)

Tatum was born in Boulder, Colorado. He received his bachelor of arts degree from the University of Chicago in 1931 and his doctor of philosophy degree from the University of Wisconsin in 1937. Then he took a year for postdoctoral study in the Netherlands.

In 1937 Tatum became a research associate in biology at Stanford University, Palo Alto, California, and received various promotions until he was appointed professor and department head in 1956.

It was at Stanford in the early 1940s that Tatum worked with Beadle on the genetics of bread mold (*Neuspora crassa*). An important conclusion from this work was that each gene produces only one enzyme. With Lederberg at Yale in 1946, he opened the field of the genetics of bacteria to modern techniques.

The Rockefeller Institute for Medical Research (now Rockefeller University) in New York City appointed Tatum a member and professor in 1957. He was elected to membership in several scientific and honorary societies, including the American Association for the Advancement of Science and the National Academy of Sciences.

TELLER, EDWARD (1908–)

Hungarian-American physicist Edward Teller is known as the Father of the Hydrogen Bomb. He was the leading member of the group that developed the principle that led to the first H-bomb.

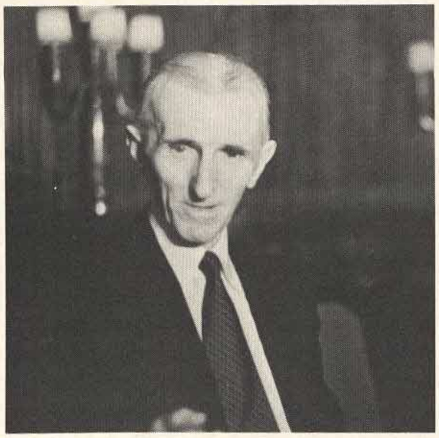
Teller was born in Budapest, Hungary, and received his doctorate at the University of Leipzig, Germany, in 1930. From 1931 to 1933 he was research associate at the University of Göttingen but left Germany after the rise of Hitler. He visited Denmark and England and moved to the United States in 1935 to become professor of physics at George Washington University in Washington, D.C. In 1941 he joined the staff of the Manhattan Project, first at Columbia University, then at the University of Chicago, and finally at Las Alamos, New Mexico. In the 1950s Teller began work on the H-bomb. While many of his colleagues feared the potential of the bomb, Teller argued strongly for its development. The exact work that Teller did in developing the bomb remained classified information.

Teller was the first chairman of the Reactors Safeguard Committee of the Atomic Energy Commission. He served as a professor of physics at the University of Chicago, 1946–1949 and 1951–1952. From 1949 to 1951 he was assistant director of the Los Alamos Scientific Laboratory. He was professor of physics at the University of California from 1953 to 1960, when he was named professor at large. In 1967 Teller was appointed assistant director of physics and head of the physics department at the radiation laboratory in Berkeley, California.

He was elected to the National Academy of Sciences in 1948 and to the American Academy of Arts and Sciences in 1954. Teller received the Atomic Energy Commission's Enrico Fermi Award in 1962. His books include *The Structure of Matter* (with F. O. Rice; 1949), *The Legacy of Hiroshima* (with Allen Brown; 1962), and *The Reluctant Revolutionary* (1964).

TESLA, NIKOLA (1857–1943)

The development and use of alternating current were in a large measure due to the efforts of the Croatian-American electrical engineer and inventor Nikola Tesla. He was considered for the 1912 Nobel Prize in physics, which he would have shared with Edison. Tesla so disliked Edison, however, that he refused to be named with him in the award, and so it was given to another scientist.



Nikola Tesla

Tesla was born in Smiljan in what is now Yugoslavia. He studied mathematics and physics at the polytechnical school in Graz, Austria, and philosophy at the University of Prague, Czechoslovakia. In 1884 he went to the United States and eventually became a naturalized citizen. He worked for several years at the Edison Company in West Orange, New Jersey. Edison promised to pay Tesla for an invention but never did, and from this arose Tesla's animosity toward Edison. Later Tesla established his own research laboratory in New York City, where he spent the rest of his life. He was a neurotic individual who was apparently more fond of pigeons, which he raised, than he was of humans.

The principle of the rotating magnetic field was conceived by Tesla, and in 1888 he applied this principle to an induction motor. He invented a transformer that would put out high-voltage electricity in the form of alternating current. It was more efficient to send alternating current over long distances than direct current, and on this basis Tesla argued for the general use of alternating current. His other inventions included a system of arc lighting and a wireless system of communications and power transmission.

THALES (640?–?546 B.C.)

Because he lived so long ago, the exact details regarding the life and work of the Greek philosopher and scientist

As indicated by a map from the time of Thales (640?–?546 B.C.), the known world at that time was limited to the area around the Mediterra-

Thales

Thales are not entirely known. He did, however, found the Ionian school of philosophy and is considered to have established Greek geometry and astronomy. In fact, some scholars regard him as the world's first scientist. The later Greeks held him in high esteem, and he was included among the so-called Seven Wise Men of Greece.

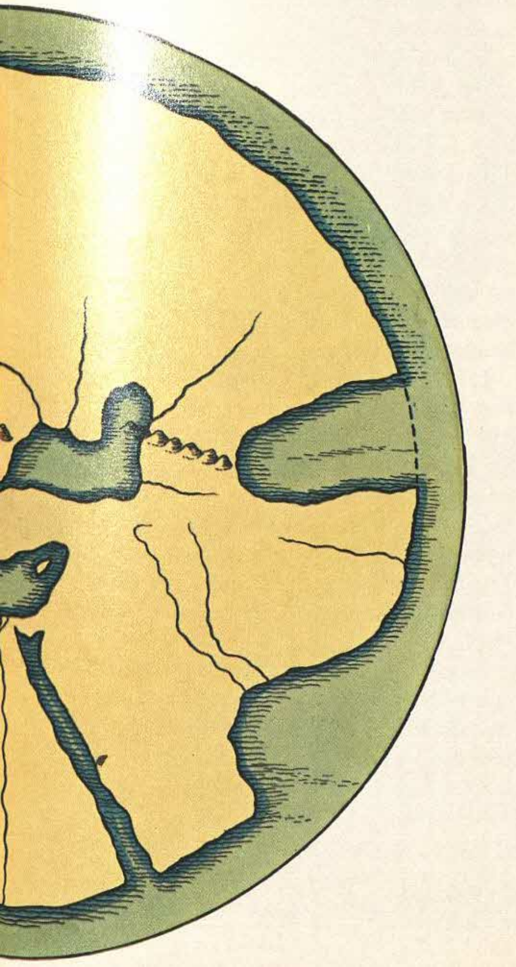
Thales was born at Miletus on the west coast of what is modern-day Turkey. It is likely that he traveled and studied in Egypt and possibly Babylonia. Also, he may have been a merchant before he turned to philosophical questions.

He began the study of philosophy by trying to find the one substance from which all things came. In answer to this self-imposed question Thales stated that the Earth was formed from a single element, water. He further taught that the Earth was a disk-shaped object floating on an infinite body of water. The great significance of this work was not in the answer but in the question. He was the first man to consider the physical aspects of the world in a rational way, without the interference of gods or myths.

In mathematics he took existing Egyptian systems and from that basis created the first abstract geometry—imaginary, one-dimensional lines. It is said that he found how to calculate the height of a pyramid by using the length of its shadow and how to tell the distance between a ship and the shore. He is also credited with the discovery of geometric theorems concerning isosceles triangles, the diameter of a circle, and the angles of intersecting lines. He was the first man known to have approached mathematical proofs with step-by-step arguments, a method that was perfected later by Euclid.

According to legend Thales became famous in his own time for predicting the solar eclipse of May 28, 585 B.C. He also proposed that the moon shines by reflected light from the sun. Early studies in magnetism are attributed to him through his discovery that lodestone attracts iron, and he is said to have discovered static electricity by noticing that amber rubbed with silk will attract light objects.

nean Sea, of which Greece was the center. To Thales, according to Aristotle, the Earth was a disk-shaped object floating on water.



THEILER, MAX (1899–   )

Microbiologist Max Theiler, whose research on the yellow fever virus led to a vaccine that protected humans against the disease, was honored for his work with the 1951 Nobel Prize in physiology or medicine.

Theiler was born in Pretoria, South Africa, and studied at Rhodes University College in Grahamstown, South Africa, and at the University of Capetown Medical School before going to St. Thomas Hospital in London and the London School of Tropical Medicine, where he received his medical degree in 1922. In that same year he joined the Department of Tropical Medicine at the Harvard Medical School in Boston, Massachusetts, where he began his extensive work on the yellow fever virus.

It had been discovered earlier that monkeys in the jungles of South America were able to transmit the disease to human beings. Theiler decided to use mice, however, in his yellow fever experiments; and eventually he was able to develop the first attenuated strain of the yellow fever virus in a common albino mouse. Further experiments produced a serum that was safe and effective for human immunization against the fever.

Theiler remained at the Harvard Medical School until 1930, when he joined the International Health Division of the Rockefeller Foundation. Eventually he became the foundation's associate director for medical and natural sciences and director of its Virus Laboratories. He left the foundation in 1964 to become professor of epidemiology and microbiology at Yale University in New Haven, Connecticut.

THEORELL, AXEL HUGO TEODOR (1903–   )

For his discoveries on the nature and mode of action of oxidative enxymes, Swedish biochemist Axel Theorell was awarded the 1955 Nobel Prize in physiology or medicine.

Theorell was born at Linköping, Sweden, the son of a physician. He studied at Karolinska Institutet in Stockholm and received his medical degree there in 1930. After serving as assistant professor of biochemistry at the University of Uppsala in 1932–1933, he went to Berlin-Dahlem, Germany, where he spent a year studying with Otto Warburg at his institute. In 1937 Theorell became a research director at Karolinska Institutet.

He had become interested in biochemistry while still a student, and in 1926 he discovered and described the lipoproteins in blood plasma. In 1932 Theorell became the first man to crystallize and describe some of the properties of myoglobin, the hemoprotein that gives the red color to certain muscles. He also purified and crystallized other hemoproteins, including cytochrome C, horseradish peroxidase, and lactoperoxidase.

Theorell crystallized the so-called "yellow enzyme" in 1934 using electrophoretic methods. He split the enzyme into two parts, the latter of which was a monophosphate ester of riboflavin (vitamin B^2), now called FMN (flavin-mononucleotide). After 1950 Theorell concentrated on alcohol dehydrogenases. He became a foreign associate of the U.S. National Academy of Sciences in 1957.

THOMPSON, SIR BENJAMIN (1753–1814)

The British physicist Sir Benjamin Thompson, or Count Rumford, became famous in the sciences for proposing that heat is a form of motion and for helping to establish the Royal Institution. He also gained fame from his adventures and his administrative posts in Great Britain and on the Continent.

Thompson was born at Woburn, Massachusetts, when the Thirteen Colonies still belonged to Great Britain. In 1766 he was apprenticed to a storekeeper in Salem, Massachusetts, but had to quit after being injured during a fireworks display. He then spent some time at Harvard University, taught in New Hampshire and Massachusetts, and educated himself somewhat in science and medicine. He also worked for a while as an assistant storekeeper in Boston. When he was eighteen years old, he married a rich widow and settled down.

In a few years, however, the American Revolutionary War broke out, and Thompson was a loyalist. When the British troops left Boston he sailed to England with them, leaving his family behind. During the war he worked for the British government as the secretary of the colony of Georgia and later as undersecretary of state. He was also busy with scientific studies and in 1779 was elected a member of the Royal Society. He was knighted in 1784.

In his researches on heat, the British physicist Sir Benjamin Thompson made use of a calorimeter that he himself had constructed.

Sir Benjamin Thompson

At the invitation of the Elector of Bavaria, Thompson entered the Bavarian civil and military service in 1784. He became the minister of war and of police and was responsible for the arsenal at Munich. It was while serving in this capacity that he came to suspect that heat is a form of motion.

Thompson was watching as brass cannons were being made and noticed that the process of boring into metal produced great heat. At that time, heat was thought of as a fluid that could be poured from one substance into another. Thompson speculated that if the mysterious fluid heat, supposedly originally contained within the brass, could be "poured" back into the metal, the metal would immediately melt. He reasoned, therefore, that heat was not inherent in the brass but was generated by the motion of the borer.

He was the first scientist to try to calculate a mechanical equivalent for heat. He also weighed water and ice and could find no difference between their weights. His scientific inventions included a calorimeter and a photometer.

The Elector of Bavaria gave Thompson the title of Count Rumford in 1791. (Rumford was the name of the Massachusetts town where his wife, who died in 1792, had been born.) In 1798 he returned to England and set about establishing the Royal Institution. He took up residence in Paris in the early 1800s and in 1805 married the widow of Antoine Laurent Lavoisier. The marriage was a failure, and they soon separated.

Thompson helped organize the Bavarian Academy of Arts and Sciences. He also established the Rumford medals of the Royal Society and of the American Academy of Arts and Sciences.

THOMSON, SIR JOSEPH JOHN (1856–1940) and SIR GEORGE PAGET (1892–)

The work of the English physicist Sir Joseph John Thomson and his son Sir George Paget Thomson, also a physicist, involved important studies of electrons. The elder Thomson is commonly regarded as the discoverer of the electron, and for his investigations into the discharge of electricity through gases he was awarded the 1906 Nobel Prize in physics. The younger Thomson discovered the diffraction of electrons by crystals, and for this work he shared the 1937 Nobel Prize in physics with C. J. Davisson. (*See* Clinton Joseph Davisson.)

The elder Thomson was born at Cheetham Hall, near Manchester, England. He was educated at Owens College, Manchester, at first studying to become an engineer; later he switched his course of study to mathematics and physics. In 1876 he entered Trinity College, Cambridge, on a scholarship. For the rest of his life he was connected with Cambridge—as a student, a professor, and a researcher.

In 1884 he became professor of physics at Cambridge. He also headed the Cavendish Laboratory, and seven of his research assistants later in their lives won Nobel Prizes. He was a professor at the Royal Institution in London from 1905 to 1918, when he returned to Cambridge to become master of Trinity College.

His first major work, which appeared in 1883, was a treatise on vortex rings; it won him the Adams Prize. His experiments using an electric charge to condense water vapor into drops was an important step toward the invention of the cloud chamber. Some of Thomson's greatest discoveries were made as a result of his interest in the effects of the discharge of electricity through gases.

In 1897 he provided the final proof that cathode rays are tiny particles. He also measured the ratio of the charge of these particles to their mass (e/m) and found that the mass of one of these particles was about 1/1000th that of the lightest atom, the hydrogen atom. At first Thomson called these small particles *corpuscles;* later he adopted the name *electron.*

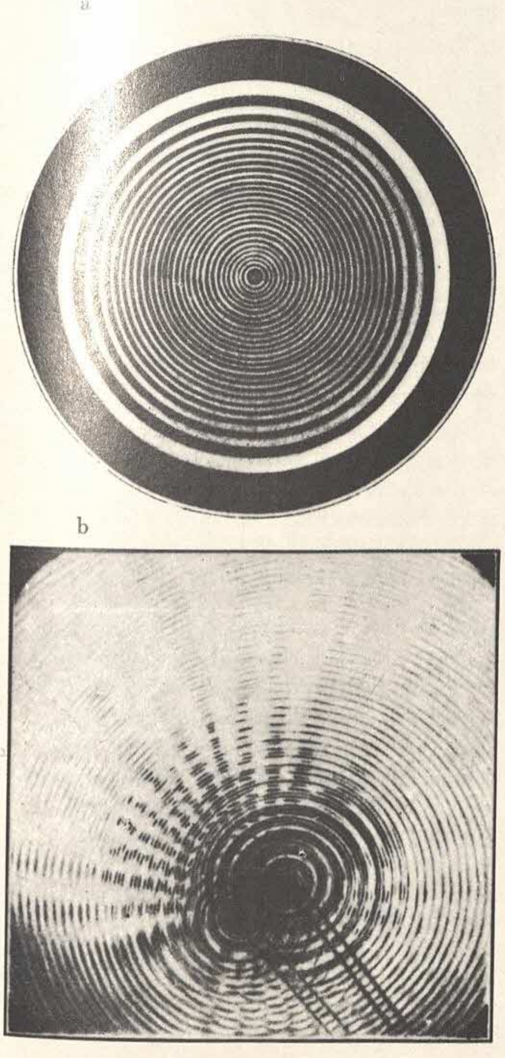
From these findings Thomson proposed one of the first theories regarding internal atomic structure. He considered the electron to be a universal component of matter. The atom, he thought, was a spherical field of positively charged electricity; enough negatively charged electrons were embedded in the field to neutralize the positive charge. For a decade

Sir Joseph Thomson

Thomson and his assistants devoted themselves to investigating the properties of electrons as conductors of electricity in gases and as essential parts of atoms.

In 1912 Thomson made another important discovery, isotopy, which opened a new area of study in atomic structure. While experimenting with the deflection of positively charged ions through electric and magnetic fields, he found that the gas neon consists of atoms of at least two different weights. These atoms came to be known as isotopes. Subsequently, many different isotopes were discovered.

The waves created by the interference of light (a) differ from those that are a result of the diffraction of electrons (b), as shown by George Paget Thomson when he passed electrons through thin metal foil.



Sir Joseph Thomson received many honors and awards during his lifetime. In 1884 he was elected a fellow of the Royal Society. He served as president of the society from 1915 to 1920. In 1908 he was knighted, and in 1912 he was awarded the Order of Merit. After his death at Cambridge, his remains were interred in Westminster Abbey, London.

Thomson's major published works include *The Application of Dynamics to Physics and Chemistry* (1888), *Elements of the Mathematical Theory of Electricity and Magnetism* (1895), *Conduction of Electricity through Gases* (1903), *Rays of Positive Electricity and Their Application to Chemical Analysis* (1913), and *The Electron in Chemistry* (1923).

The younger Thomson, only son of Sir Joseph John, was born at Cambridge and took his degree at Trinity College in 1914. During World War I he served for a short time as an infantry officer in France and then conducted research on aerodynamics for the government. In 1922 he became professor of physics at the University of Aberdeen in Scotland.

While at Aberdeen he learned of De Broglie's theory regarding the wave properties of electrons. Thomson had been doing studies on the scattering of protons produced in a gaseous discharge under low pressure. By reversing the polarity of the discharge he was able to pass cathode rays through thin metal foil, thereby obtaining his results on the diffraction of electrons. Analysis of the photographic patterns produced from these experiments supported De Broglie's electron-wave theory.

From 1930 to 1952 he was professor of physics at the Imperial College of Science and Technology in London. During World War II he was chairman of the British Commission on Atomic Energy, and after the war he devoted some time to the study of controlled thermonuclear reactions. From 1952 until his retirement in 1962 he was master of Corpus Christi College, Cambridge.

In 1930 he was elected a fellow of the Royal Society. He received the Hughes Medal in 1939 and the Royal Medal in 1949. In 1943 he was knighted. His published works include *Applied Aerodynamics* (1919), *Wave Mechanics of the Free Electron* (1930), *The Atom* (1930), and *Theory and Practice of Electron Diffraction* (1939).

THOMSON, SIR WILLIAM (1824–1907)

The British mathematician and physicist Sir William Thomson was active in many areas of experimental and theoretical physics. He discovered the second law of thermodynamics, suggested the absolute scale of temperature, and made improvements in telegraphic instruments. His work on electric signals was particularly important to the success of the Atlantic cable.

The British scientist Sir William Thomson made many contributions to physics, especially in the area of thermodynamics. It is for his work in telegraphy, however, that he is best known; he was largely responsible for the laying of the first Atlantic cable.

Thomson was born at Belfast, Ireland. His father was professor of mathematics at the University of Glasgow; and when Thomson was eight years old, he began attending his father's lectures. At age eleven he entered the University of Glasgow but transferred to Peterhouse, Cambridge, in 1841. After graduating in 1845, he went to Paris to study experimental physics and in 1846 was appointed professor of natural philosophy at Glasgow, where he remained until his retirement in 1895.

Some of his earliest work dealt with the age of the Earth. He theorized that the Earth broke away from the sun; and basing his figures on the length of time necessary for the Earth to cool down to its present temperature, he concluded that the Earth was probably about 100 million years old. This theory, announced in 1846, touched off a long controversy between geologists and Thomson's supporters.

In 1847 Thomson met J. P. Joule, whose work on heat had a strong influence on him. Together the two men worked on the Joule-Thomson effect, regarding the temperature drop in gases expanding into a vacuum. This later became important in attaining extremely low temperatures.

Extending his work in this area, Thomson suggested that the energy of gas molecules, not the volume of the gas, reached zero at −273° C. This led to the introduction of the term *kinetic energy*. Thomson further suggested that −273° C be considered absolute zero and in 1848 introduced the absolute, or Kelvin, scale of temperature. (Since then absolute zero, the lowest temperature possible, has been set at −273.18° C.)

In a paper on the dynamics of heat (1851), Thomson presented the principle of the law of the conservation of energy and the second law of thermodynamics. He concluded that all energy is dissipated in the form of heat and that therefore the universe is burning itself out.

To the general public, however, Thomson was most famous for his work on telegraphy, especially the laying of the first Atlantic cable. Thomson suggested the use of a stranded form of copper conductor and presented the rule that the speed of signaling is inversely proportional to the square of the length of the cable. He also invented the mirror galvanometer and the siphon recorder for telegraphy and introduced the telephone to Great Britain.

Among his many other inventions were an improved marine compass, a gyrostat, sounding gauges, tide predictors, the Kelvin standard balance (a type of dynamometer), and a quadrant electrometer. Thomson also applied mathematics to electric oscillation and worked on the theory of electromagnetism. In his last years he became very conservative, stating that all the important discoveries in physics had already been made. He never believed that energy is released from radioactive atoms.

For his contributions to telegraphy he was knighted in 1866; and in 1892 he was raised to the peerage, becoming Baron Kelvin of Largs (Scotland). In 1877 he was elected a foreign associate of the French Academy of Sciences, from 1890 to 1894 he served as president of the Royal Society, and in 1902 he was awarded the Order of Merit. After his death he was honored with burial in Westminster Abbey, next to Sir Isaac Newton.

THORNDIKE, EDWARD LEE (1874–1949)

The U.S. psychologist Edward Lee Thorndike developed theories of learning that influenced educators in favor of social utility. He was a prolific writer, producing more than 500 books and articles in his lifetime. His best-known work was probably *Educational Psychology*, which was published in three volumes in 1913–1914. He wrote also on the theory of psychological testing; vocational counseling; and the determination of wants, needs, interests, and aptitudes.

His work in the field of animal intelligence was very important, particularly his studies of behavior in monkeys. Other interests included arithmetic, handwriting, and language.

Thorndike was born in Williamsburg, Massachusetts. He received a bachelor's degree from Wesleyan University, Middletown, Connecticut, in 1895, a master's degree from Harvard University in 1897, and a doctorate from Columbia University, New York City, in 1898. After teaching for a year at Western Reserve University, Cleveland, Ohio, he moved to a post at the Teachers College of Columbia, where he spent the rest of his career except for those times when he was a visiting lecturer at Cornell University, Ithaca, New York; Johns Hopkins University, Baltimore, Maryland; and Yale University. In 1904 he was appointed professor.

Recognized as a great authority by his colleagues, he was elected president of the Psychological Association in 1912. He also served as president of the New York Academy of Sciences and the American Association for the Advancement of Science (1934). Thorndike received honorary degrees from many institutions of higher learning, including Wesleyan, Harvard, Edinburgh University in Scotland, and the State University of Iowa.

THURET, GUSTAVE ADOLPHE
(1817–1875)

The French botanist Gustave Thuret is noted for his work on the reproduction of algae. In 1840 his first paper appeared, detailing the discovery of flagella of spermatozoids in the green algae *Chara;* four years later, together with the French algologist Joseph Decaisne, he announced finding spermatozoids in the brown algae *Fucus;* and in 1854 he gave the first accounts of fertilization and hybridization in *Fucus.* With Édouard Bornet, another French algologist, in 1867, he determined the life cycle of Florideae, a group of red algae.

Thuret was born in Paris. After receiving a law degree in 1838, he studied under Decaisne. In 1840 he went to Constantinople as French attaché but returned to France within a short time and devoted himself to science. He spent much time studying algae on the Atlantic coast of France; but in 1857 he moved to Antibes on the Riviera, where he established an outstanding botanic garden. His *Études phycologiques* was published posthumously in 1878.

TISELIUS, ARNE WILHELM KAURIN
(1902–   )

The Swedish biochemist Arne Tiselius is best known for his research on electrophoresis and adsorption analysis. For this work, especially his discoveries about the complex nature of the serum proteins, he was awarded the 1948 Nobel Prize in chemistry.

The long hours that Arne Tiselius spent in the laboratory doing research on electrophoresis and adsorption analysis led to his discoveries about the complex nature of serum proteins.

Tiselius was born in Stockholm, Sweden, and studied chemistry and physics at the University of Uppsala, where he received his doctorate in 1930. While a student, he worked with Theodor Svedberg, a famous chemist who became a Nobel laureate in 1926. From 1930 to 1938 Tiselius was a lecturer in the Institute of Physical Chemistry at Uppsala. As a Rockefeller Foundation fellow, Tiselius visited the United States in 1934 and 1935, working at the Institute for Advanced Study at Princeton University in New Jersey. In 1937 he returned to Uppsala and became a professor of biochemistry. He was chairman of the Swedish State Council for Research in Natural Science from 1946 to 1950, became vice president of the Nobel Foundation in 1947, and was elected a foreign associate of the U.S. National Academy of Sciences in 1949.

TISSERAND, FRANÇOIS FÉLIX (1845–1896)

The French astronomer François Tisserand is best remembered for his theoretical researches and his excellent textbooks. In the course of his studies, he took part in various astronomical expeditions, going to Malacca to observe the total solar eclipse of August 1868 and to Japan and Martinique in 1874 and 1882, respectively, to observe the transits of Venus.

Tisserand was born at Nuits-Saint-Georges, Côte-d'Or, and studied science at the École Normale Supérieure in Paris. In 18[illegible] he was appointed assistant to Urbain Leverrier at the Paris Observatory; in 1873 he became director of the observatory at Toulouse; in 1878 he succeeded Leverrier in the Académie des Sciences, and in 1892 he returned to the Paris Observatory, this time as director.

While in that capacity, he completed the reobservation of the Lalande catalogs and the organization of the work on the international photographic catalog *Carte du Ciel*. Meanwhile, he continued working on his best-known textbook, *Traité de mécanique céleste* (four volumes; 1889–1896). In addition, in 1884 he founded the astronomical journal *Bulletin astronomique*, containing his work on the theory of the capture of periodic comets.

TITCHENER, EDWARD BRADFORD (1867–1927)

The British-U.S. psychologist Edward Bradford Titchener was a leader of the structural school of psychology. He stressed the need for experiments and for controlled introspection.

Titchener was born at Chichester, England, and educated at Brasenose College, Oxford, and at Leipzig University in Germany, where he received his doctorate in 1892. The following year he moved to the United States and joined the faculty of Cornell University, Ithaca, New York, as assistant professor of psychology. In 1895 he was named Sage Professor of Psychology there, and in 1909 he was appointed to another professorship in the graduate school.

While at Cornell he published 8 books and more than 200 articles. His chief work was probably *Experimental Psychology*, published in four volumes from 1901 to 1905. He also wrote *An Outline of Psychology* (1896), *Lectures on the Elementary Psychology of Feeling and Attention* (1908), and *A Textbook of Psychology* (1910), as well as edited the *American Journal of Psychology* for more than thirty years.

Titchener was a member of the Zoological Society of London, the Royal Society of Medicine, and the Polish Academy of Arts and Sciences. In 1904 he founded the Society of Experimental Psychology.

TODD, SIR ALEXANDER ROBERTUS (1907–)

The British chemist Sir Alexander Todd conducted extensive research on chemical substances of biological interest. His work concerning the structure and synthesis of nucleosides, nucleotides, and nucleotide coenzymes earned him the 1957 Nobel Prize in chemistry.

He was born in Glasgow, Scotland, and received his education at the University of Glasgow and the University of Frankfurt in Germany, where he obtained his doctorate in 1930. Before joining the staff of the Lister Institute of Preventive Medicine in London, he did research at Edinburgh University in Scotland from 1934 to 1936. He was named professor of chemistry and chairman of the department at Manchester University in England in 1938, became professor of organic chemistry at Cambridge University in 1944, and in 1963 was appointed master of Christ's College.

Todd's chemical research led him to a successful explanation of the constituents of vitamin B_1, vitamin E, and hashish. His work on the structure and synthesis of nucleosides and nucleotides contributed much to the knowledge of the structure and biological function of acids.

He was elected to the Royal Society of London in 1942, and in 1955 he was elected a foreign associate of the U.S. National Academy of Sciences. From 1952 to 1964 he served as chairman of the British government's Advisory Council on Scientific Policy. Todd was knighted in 1954 and became Baron of Trumpington in 1962.

TOLMAN, EDWARD CHACE (1886–1959)

The U.S. psychologist Edward Tolman developed the idea of purposive behaviorism. In contrast with John B. Watson, who defined the unit of behavior as a simple conditioned reflex, Tolman believed it to be complex and to include a goal-oriented series of body movements guided by cognitive processes, all this activity taking place for specific purposes. His chief work was *Purposive Behavior in Animals and Men* (1932).

Tolman was born at West Newton, Massachusetts, and educated at the Massachusetts Institute of Technology, Cambridge, and at Harvard. After receiving his doctorate from the latter school in 1915, he became an instructor in psychology at Northwestern University, Evanston, Illinois. In 1918 he went to the University of California at Berkeley, where he stayed until his retirement in 1954, being promoted to assistant professor in 1920, associate professor in 1923, and professor in 1928. His affiliations included membership in the Psychological Association and the American Association for the Advancement of Science.

TOMONAGA, SHIN'ICHERŌ (1906–)

The Japanese physicist Shin'icherō Tomonaga shared the 1965 Nobel Prize in physics with two Americans, J. S. Schwinger and R. P. Feynman. He was the second Japanese to win the award. The three, working independently during the early 1940s, conducted similar research in quantum electrodynamics. They solved difficulties involved in carrying out quantitative calculations of the interplay between charged particles; they reworked the formalism of electrodynamics, using methods that made calculation easier; and they showed that the divergences appearing in physical quantities were all consequences of two fundamental divergences, those in the corrections to the mass and charge of the electron arising from its interaction with photons. (*See* Richard Phillips Feynman; Julian Seymour Schwinger.)

Shin'icherō Tomonaga

Tomonaga was born in Tokyo, Japan, the son of a philosopher and professor. He attended Kyoto University and later did research at the Science Research Institute in Tokyo and with Werner Karl Heisenberg in Germany. In 1941 he became professor at the Tokyo Education University and served as its president from 1956 to 1962. A year later he was made chairman of the Japan Science Council.

TORREY, JOHN (1796–1873)

The U.S. botanist and chemist John Torrey is known as the originator of the great work *Flora of North America.* He also helped found, in 1817, the Lyceum of Natural History, forerunner of the New York Academy of Sciences.

Torrey was born in New York City and educated at the College of Physicians and Surgeons there. After receiving his medical degree in 1818, he practiced for only a short time, instead holding professorships in chemistry at his alma mater (1827–1855) and in chemistry and natural history at Princeton University, New Jersey (1830–1854). In addition, he became New York State botanist in 1836, and from 1853 to 1873 was chief assayer to the U.S. Assay Office in New York City.

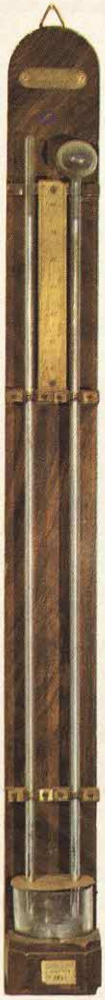
Besides collaborating with Asa Gray on the early volumes of *Flora of North America* from 1838 to 1843, Torrey also issued a monograph on the Cyperaceae in 1836 and produced *Flora of the State of New York* in 1843. In about 1860 he gave his botanical library and herbarium to Columbia University in New York City. These were transferred in 1899 to New York Botanical Garden. During his lifetime he was honored with the founding of the Torrey Botanical Club.

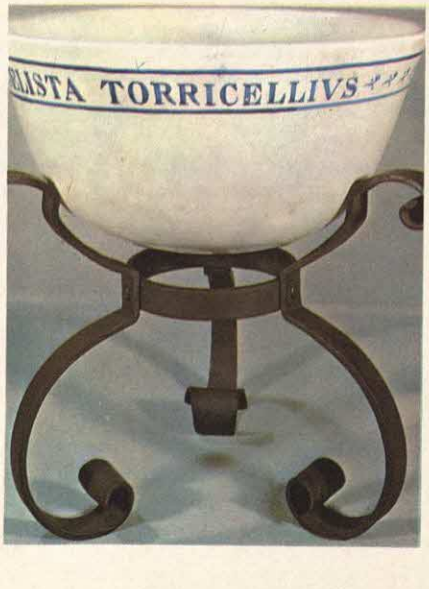
TORRICELLI, EVANGELISTA (1608–1647)

The principle of the barometer was discovered by the Italian mathematician Evangelista Torricelli, who also devised a mercury barometer. In other areas he worked on the properties of a cycloid, made a simple microscope, introduced some improvements in the telescope, and produced written works on fluid motion, the theory of projectiles, and fixed pulleys.

While studying vacuums, Torricelli inadvertently discovered the principle of the barometer. He was investigating the possibility that water could be pumped upward because of the weight of air pressing on the water outside the pump, rather than because of some natural need to fill a vacuum. With a vacuum pump, water could be raised to only about thirty-four feet. Torricelli devised an experiment using mercury, which is 13.6 times as heavy as water. He filled a long tube with mercury and stood it upright with the open end in a dish of mercury. Some of the mercury ran out, leaving a column of mercury about thirty inches high. The space between the mercury and the end of the tube constituted the first man-made vacuum. Torricelli attributed the daily variations in the height of the mercury to daily variations in atmospheric pressure. Thus, he had invented the world's first barometer.

Evangelista Torricelli's first barometer, consisting of a long tube of mercury standing upright in a dish of mercury, was the model for later, refined mercury barometers.





Evangelista Torricelli

Torricelli was born at Faenza, near Ravenna. Apparently he was an orphan and received his early education from the Jesuits, but in 1627 he went to Rome to study mathematics and science. On first reading the works of Galileo in 16[illegible] he was greatly impressed; and a mutual admiration sprang up between the two men, for Galileo, in turn, was impressed by Torricelli's book on mechanics and in 1641 invited Torricelli to come to Florence. For the last three months of Galileo's life, Torricelli worked as his assistant and, after his death, took his place as mathematician to the grand duke of Tuscany and professor at the Florence Academy.

TOWNES, CHARLES HARD (1915–)

The U.S. physicist Charles Townes was awarded the 1964 Nobel Prize in physics for his invention of the maser (*m*olecular *a*mplification by *s*timulated *e*mission of *r*adiation). He shared the prize with Soviet physicists Nikolai Basov and Aleksandr Prokhorov, who did fundamental research on the maser-laser principle. (*See* Nikolai Gennadievich Basov; Aleksandr Mikhaylovich Prokhorov.)

The maser employs molecules to amplify electromagnetic waves or to produce electromagnetic oscillation. (The laser operates on the same principle but uses light instead of molecules.) Secondary waves are thus initiated, and these must be of great speed. Masers have been invaluable in amplifying faint radio waves in communications and for use in atomic clocks.

With a background in radar, Townes was well equipped to study microwave amplification. During World War II he worked on radar and on computers. Advanced electronic oscillators were being developed at that time through radar technology. He used microwave oscillators again after the war, in the field of microwave spectroscopy. By 1951 Townes had created a system of molecules for amplifying radiation at short wavelengths. With two colleagues at Columbia University, New York City, he built the first maser in 1954.

Townes, the son of a lawyer, was born at Greenville, South Carolina, where he studied physics and modern languages at Furman University, receiving a bachelor of arts degree and a bachelor of science degree in 1935. After receiving a master's degree in physics from Duke University at Durham, North Carolina, in 1937, he proceeded to earn a doctorate in physics at the California Institute of Technology, Pasadena, in 1939. From 1939 to 1947 he worked as a physicist on the staff of Bell Telephone Laboratories. He joined the faculty of Columbia University in 1948, serving as director of its radiation laboratory for two years and as chairman of the physics department for five years. Taking a leave of absence, he became a vice-president and director of research of the Institute for Defense Analyses, Washington, D.C., in 1959 and remained in that post for two years. In 1961 he was appointed provost and professor of physics at the Massachusetts Institute of Technology, Cambridge.

TOWNSHEND, CHARLES TOWNSHEND, SECOND VISCOUNT (1674–1738)

The British statesman Charles Townshend was also a noted agricultural specialist. Because of his interest in promoting the use of turnips in agricultural practice, he earned the nickname "Turnip Townshend." He promoted the use of the turnip as winter fodder and emphasized its role in a four-course rotation system, whereby farmers could plant turnips on the portion of their land that they would ordinarily keep fallow in a rotation system.

Townshend was born at Raynham, Norfolk, and educated at Eton and at King's College, Cambridge University. During his school days he began a close association with Robert Walpole, later the earl of Orford. He and Walpole carried on busy political careers as Whigs, and in 1713 he married Walpole's sister Dorothy. Townshend served as secretary of state from 1714 to 1716 and again from 1721 to 1730. One of his most noteworthy diplomatic achievements was to provide a balance to the Vienna Alliance between Austria and Spain by promoting the League of Hanover, an alliance of England, France, and Prussia.

TRAUBE, ISIDOR (1860–1943)

The German physical chemist Isidor Traube is considered the founder of capillary chemistry. He made advances in critical temperature studies, osmosis, colloids, and surface tension. His practical interests included physical chemical studies of gastric juice, urine, blood, and milk. To help him in his work, he designed a viscometer and a capillarimeter. The rule that he formulated, which can be applied to various investigative studies, states that the surface tension of capillary active organic compounds belonging to one homologous series decreases with each additional CH_2 group in a constant ratio, which is about three to one.

Traube was born at Hildesheim and educated at the University of Berlin, where he received his doctorate in 1882. Eight years later he had attained a professorship at the Technische Hochschule in Berlin.

TREVITHICK, RICHARD (1771–1833)

An English engineer and pioneer builder of high-pressure steam engines, Richard Trevithick is remembered as the Father of the Locomotive. In 1801, at Camborne, he built the first high-pressure steam road carriage; and in 1802 he and a cousin, Andrew Vivian, took out a patent for the high-pressure engine for both stationary and locomotive use.

Trevithick was born near Illogan, Cornwall, to a mining family; and by the time that he was nineteen years of age, he was a successful mining engineer. He demonstrated his first steam carriage at Beacon Hill on Christmas Eve 1802, but only three days later it was destroyed by fire. In 1803 he demonstrated his second one in London; but since no one seemed impressed, he returned to mining, building stationary engines and constructing a steam locomotive to haul iron and miners on a ten-mile tramway connecting Abercynon and Merthyr Tydfil, Wales.

From 1813 to 1827 he traveled in South America—Peru, Chile, and Colombia—building high-pressure engines and working in the mines there; however, he returned penniless. He is commemorated at Camborne with a statue and in London with a memorial window at Westminster Abbey.

TRUMPINGTON, BARON TODD OF.

See Todd, Sir Alexander Robertus.

TRUMPLER, ROBERT JULIUS (1886–1956)

The Swiss-born U.S. astronomer Robert Trumpler is known for his extensive research on galactic star clusters, for observational tests of the relativity theory, and for his study of Mars. An accurate observer, he discovered the differences in galactic clusters used to determine their ages and proved that a tenuous interstellar haze exists in the Milky Way and dims the light of stars seen through it.

Trumpler was born in Zürich and educated there and in Germany. From 1919, when he joined the staff of the Lick Observatory, until 1951, when he retired as professor emeritus, he was connected with the University of California, at the Berkeley campus from 1938.

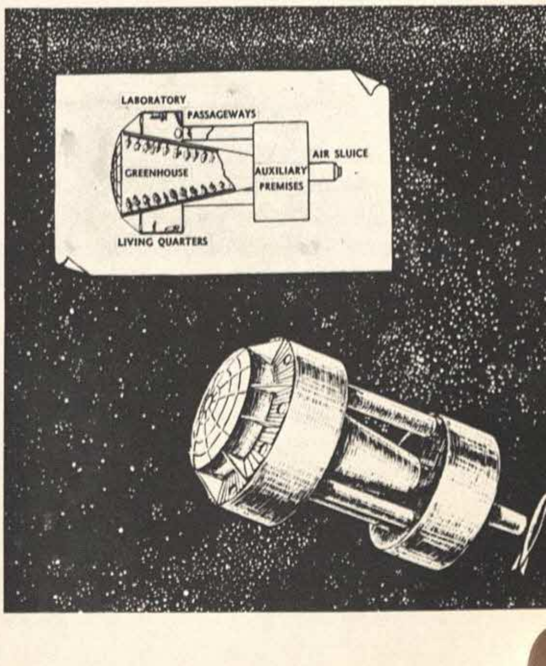
His publications include *Observations of the Deflection of Light Passing through the Sun's Gravitational Field* (with W. Campbell; 1923); *Spectral Types in Open Clusters* (1925); *Observations of Mars at the Opposition of 1924* (1927); *Preliminary Results on the Distances, Dimensions, and Space Distribution of Open Star Clusters* (1930); and *Observational Evidence of a Relativity Red Shift in Class O Stars* (1935).

TSIOLKOVSKY, KONSTANTIN EDUARDOVITCH (1857–1935)

As early as the mid-1890s, space flight was seriously considered a possibility by the farsighted Russian physicist Konstantin Tsiolkovsky. By 1898 he was convinced of the superiority of liquid-fueled rockets over those powered by solid fuels.

Konstantin Tsiolkovsky

In his book *The Exploration of Cosmic Space by Means of Reaction Motors*, which he began in 1898, the space-science pioneer Konstantin Tsiolkovsky, with great farsightedness, presented such advanced concepts as space stations and staging by booster rockets.



He was also the first man to suggest the construction of a space station.

Tsiolkovsky was born at Izhevsk, Ryazan Province, Russia. Due to scarlet fever he became almost totally deaf at age nine and as a result was tutored at home. In mathematics and physics he was largely self-taught. When he was sixteen years old, he went to Moscow to study astronomy, chemistry, mathematics, and physics. By using an ear trumpet that he had made himself, he was able to attend lectures.

In 1876 he began teaching mathematics at Borovsk, near his native village. He worked out the kinetic theory of gases and in 1881 submitted his findings to the St. Petersburg Society of Physics and Chemistry, but he was informed that this work had been done earlier by James Clerk Maxwell.

Undaunted, in 1882 he moved to Kaluga, where he accepted a teaching position and settled down to do research in aeronautics and astronautics. He constructed a wind tunnel and investigated the aerodynamics of airfoils. Dirigibles were of particular interest to him.

His thinking was far ahead of his time in the fields of rocketry and space flight. He developed the theory of mass ratio, and his book *The Exploration of Cosmic Space by Means of Reaction Motors* presented such concepts as the vector control of rockets by vanes in the exhaust. He also presented the method of staging by booster rockets.

TULL, JETHRO (1674–1741)

The English agriculturist Jethro Tull initiated major improvements in farming practices in his country. He was the inventor of a seed drill that sowed seeds in rows, allowing cultivation between the rows. The drill was a great step toward the mechanization of cultivation and was described in Tull's book *The New Horse Houghing Husbandry* (1731). Tull also initiated the use of a horse-drawn hoe to uproot weeds from the growing crop.

Although his methods saved seed and successfully curbed the weed crop, they were strongly attacked at first. Eventually, however, they were adopted by many large landowners in England. One of Tull's early admirers was the French philosopher Voltaire, who used the new methods on the farmlands of his estate.

Tull was born at Basildon, Berkshire, and educated at St. John's College, Oxford University. Having read law at Gray's Inn, London, he was called to the bar in 1699. About two years later he began farming an estate at Hawberry, near Wallingford, Oxfordshire; and in 1709 he moved to Prosperous Farm, near Hungerford, Berkshire, where he remained for the rest of his life.

TURNER, HERBERT HALL (1861–1930)

The English astronomer Herbert Hall Turner pioneered in many procedures universally used in measuring astronomical photographs. He is known for his introduction of standard coordinates in the reduction of astronomical photographs and for his work in helping complete the Oxford and other zones of the astrographic catalog.

Turner was born at Leeds, Yorkshire, and educated at Trinity College, Cambridge, of which he later became a fellow. In 1884 he was named chief assistant at the Royal Observatory, Greenwich, and remained there until 1893, when he went to Oxford as Savilian Professor of Astronomy and director of the University Observatory.

His publications include more than 200 papers and essays on astronomy and seismology. In addition, he contributed monthly to the periodical *Observatory* under the heading "From an Oxford Notebook."

TYNDALL, JOHN (1820–1893)

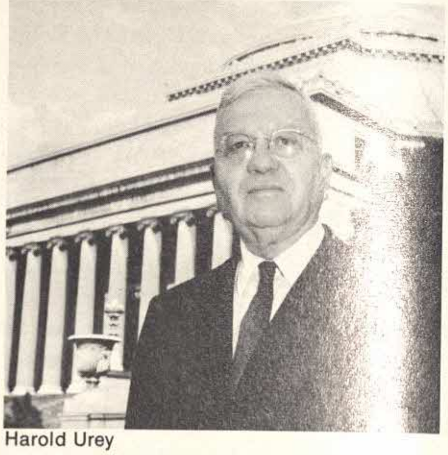
Although best known for his work on radiant heat, the British natural philosopher John Tyndall established the absorptive power of clear aqueous vapor, an important advance in meteorology, and conducted brilliant experiments on the blue of the sky, discovering the precipitation of organic vapors by means of light. He also did work on magnetism and verified that germ-free air cannot initiate putrefaction.

Tyndall was born at Leighlin Bridge, Carlow, Ireland, and received his doctorate at the University of Marburg, Germany, in 1850. Three years later he became natural philosophy professor at the Royal Institution in London, and from 1867 until his retirement in 1887 he served as its superintendent.

In 1852 Tyndall was elected to membership in the Royal Society. Among his many books are *Heat Considered as a Mode of Motion* (1863), *On Sound* (1867), and *Lessons in Electricity, at the Royal Institution* (1876).

UREY, HAROLD CLAYTON (1893–)

The U.S. chemist Harold Urey was the discovered of deuterium, principal source of power for the hydrogen bomb. This discovery earned him the 1934 Nobel Prize in chemistry.



Harold Urey

After the discovery of deuterium early in his career, Urey developed procedures for separating heavy isotopes of carbon, oxygen, nitrogen, and sulfur. As director of research for the Substitute Alloy Materials Laboratories at Columbia University, New York City, during World War II, he led a group responsible for separating uranium isotopes for the Manhattan Project.

Urey was born at Walkerton, Indiana, the son of a rural schoolteacher, and attended the University of Montana, where he received his bachelor's degree in 1917 and spent two years as an instructor. After receiving his doctorate in chemistry from the University of California in 1923, he went to Copenhagen, Denmark, as a fellow at Niels Bohr's Institute of Theoretical Physics. In 1924 he became an associate in chemistry at Johns Hopkins University, Baltimore, Maryland; from 1929 to 1945 he was on the faculty of Columbia University in New York City; and in 1945 he joined the newly organized Institute for Nuclear Studies and the Department of Chemistry at the University of Chicago. He remained there until 1958, when he became professor of chemistry at large at the University of California.

Urey was elected to the National Academy of Sciences in 1935. His publications include *Atoms, Molecules, and Quanta* (with Ruark, 1930; revised edition, 1964) and *The Planets* (1952).

VAN ALLEN, JAMES ALFRED (1914–)

While studying data being broadcast from the first U.S. satellite, *Explorer I*, the U.S. physicist James Van Allen discovered that the Earth is surrounded by intense belts of radiation thousands of miles wide. Later investigation revealed that the belts consist of electrically charged particles trapped in magnetic fields in the heavens. The belts were named in honor of their discoverer.

Using rockets and balloons, Van Allen began studying cosmic-ray phenomena as early as 1946. Ten years later he helped design the internal instruments for the IGY (International Geophysical Year) satellites. His discovery of the now famous radiation belts and his explanation of their origin opened up a whole new area of study and paved the way for magnetosphere exploration.

Van Allen was born at Mount Pleasant, Iowa, and educated at Iowa Wesleyan College and the University of Iowa. On receiving his doctorate in 1939, he became a research fellow of the Department of Terrestrial Magnetism at Carnegie Institute of Technology in Pittsburgh. In 1946, after serving as a naval officer in World War II, he went to Johns Hopkins University, Baltimore, Maryland, to head a research group at its applied physics laboratory. He returned to the University of Iowa in 1951 as professor and chairman of the physics department. Van Allen received the Louis W. Hill Space Transportation Award of the Institute of the Aerospace Sciences in 1959 and was elected to the National Academy of Sciences that same year.

Although James Van Allen (right) is examining a sounding device of the *Pioneer* type with Wernher von Braun (left), it was while working with data broadcast from *Explorer I* that he discovered the Van Allen radiation belts.

VAN DER WAALS. See Waals, Johannes Diderik van der.

VAN LEEUWENHOEK. See Leeuwenhoek, Anton van.

VAN'T HOFF, JACOBUS HENRICUS

(1852–1911)

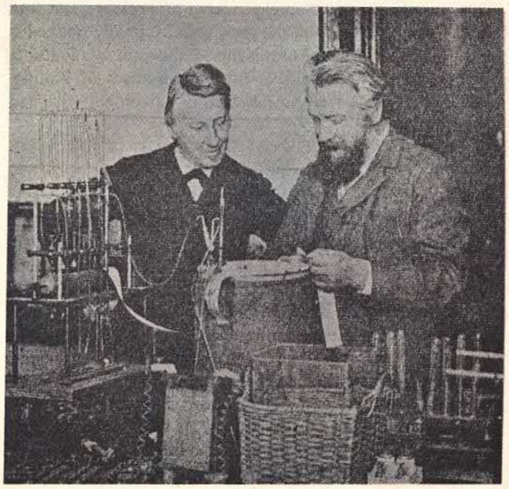
The first man to win a Nobel Prize in chemistry was Jacobus van't Hoff of the Netherlands; he was honored in 1901, the year the awards were established. His discoveries about the optical activity of substances in solution and his contributions to the study of chemical thermodynamics also earned him the Royal Society's Davy Medal in 1893 and membership in the society four years later.

Van't Hoff's name is often linked with that of French chemist Joseph Achille le Bel because both men, then students together at the École de Médecine in Paris, almost simultaneously reached the same conclusions about the structure of organic compounds. Prior to the publication of Van't Hoff's theory in September 1874 and Le Bel's just two months later, scientists had puzzled over the fact that some organic compounds are optically active while others are not. It was Van't Hoff who first suggested that asymmetry in molecules is the reason for this inconsistency.

By drawing the four valences of the carbon atom three dimensionally to the angles of a regular tetrahedron rather than two dimensionally to the angles of a square, Van't Hoff provided a solution to the puzzle. An earlier observation of the phenomenon of polarized light was the key to his revelation. He knew that tartaric acid exists in two forms, chemically identical but physically different: one rotates the plane of polarization of a polarized light beam to the left; the other to the right. This mirror-image rotation was elucidated by Van't Hoff's explanation that two asymmetric compounds result when four different types of groupings are attached to the four bonds of the carbon atom; only these particular compounds show optical activity or rotation.

Van't Hoff, a Rotterdam native, was determined to become a chemist despite the objections of his physician father. He began his education at the Delft Polytechnic but transferred to the University of Leiden in 1871. The following year he went to Bonn, Germany, to study under Friedrich A. Kekulé and then to Paris, where he made his mark in the area of stereochemistry.

Two years after publishing his explanation of optical activity, Van't Hoff returned to the Netherlands to serve as a lecturer at the Veterinary College at Utrecht; and in 1878 he became full professor of chemistry, mineralogy, and geology at Amsterdam University. During his eighteen years at Amsterdam, he turned his attention to the field of thermodynamics, with particular emphasis on the theory of solutions in relation to reaction kinetics and the attainment of equilibrium. Here his primary achievement was a lucid statement, published in 1884 in *Studies of Dynamic Chemistry*, on the relationship between the osmotic pressure of solutions and their vapor pressure.



Jacobus van't Hoff (left) early became a close friend of F. W. Ostwald (right), with whom in 1887 he founded *Zeitschrift für physikalische Chemie*, long the leading journal in its field.

Further research in the area of dilute solutions produced examples of how simple laws governing the behavior of gases are also applicable to the sparsely dissolved material in liquid solvents. This similarity between dissolved molecules moving in liquid and gas molecules moving in space was established in a paper published by Van't Hoff in 1886.

He went to Germany in 1896 to become an honorary professor at the Prussian Academy of Sciences in Berlin. Until his death there in 1911, he studied the salt mixtures in the Stassfurt deposits, as well as lectured on them. The results of this final research project proved useful to Germany's chemical industries.

VAUBAN, SÉBASTIEN LE PRESTRE DE

(1633–1707)

Although famous as marshal of France under King Louis XIV, Sébastien Vauban is remembered as one of the most celebrated military engineers of all time. After his successful siege of Stenay in 1654, Vauban was made a king's engineer in 1655 and thereafter occupied himself with brilliantly executed sieges in the Dutch Wars from 1667 to 1697 and with redesigning or building at least 160 fortifications throughout France. His innovative systems for siege work and fortification were the focus of military studies for more than a century.

Vauban was born at Saint-Léger-de-

Foucherest in Burgundy, near his grandfather's castle of Vauban. At eighteen years of age he received a cadetship and began his long and brilliant military career.

Before he retired in 1706, Vauban had written treatises on river navigation, forestry, rehabilitation of the colonies, a project for general peace, the recall of the banished Huguenots, and fairer taxation. His *Projet d'une dixme royale* called for a substitution of the oppressive taille and other taxes by a royal tithe from which no class would be exempt. This work was banned from public sale, but several editions were circulated privately.

VAUQUELIN, NICOLAS LOUIS
(1763–1829)

In 1797 the French analytical chemist Nicolas Vauquelin discovered chromium in a lead ore from Siberia; and it is for this that he is best known, though he made numerous other discoveries as well. He recognized the existence of beryllium in the gems beryl and emerald but did not actually isolate it. In what proved to be the first discovery of an amino acid, he isolated the compound asparagine from asparagus in 1806. His other discoveries included camphoric acid, quinic acid, and other naturally occurring organic compounds.

Vauquelin was born at Saint-André d'Hébertot in Normandy, the son of a poor peasant. From 1777 to 1779 he was apprenticed to an apothecary's shop in Rouen; and from 1783 to 1791 he served as laboratory assistant to the experimental chemist Antoine Fourcroy, also becoming his friend and colleague. Beginning in the mid-1790s, Vauquelin held a number of teaching and consultative positions, finally succeeding Fourcroy as professor of chemistry to the medical faculty of Paris.

Besides chemistry, Vauquelin was interested in literature, art, and politics. He was always strongly republican; but during the French Revolution he rescued a Swiss soldier from the mob and had to leave France during the worst of the Terror (1793–1794), since he could well have been guillotined for this act. In 1827 he was elected to the Chamber of Deputies, and in 1795 he was elected to the Académie des Sciences.

VESALIUS, ANDREAS (1514–1564)

The Flemish anatomist Andreas Vesalius was the undoubted founder of modern anatomy, being one of the first men to dissect the human body. For this he was eventually sentenced to death; but his teachings took hold in the minds of his medical contemporaries, and from that time real progress was made in the biological sciences.

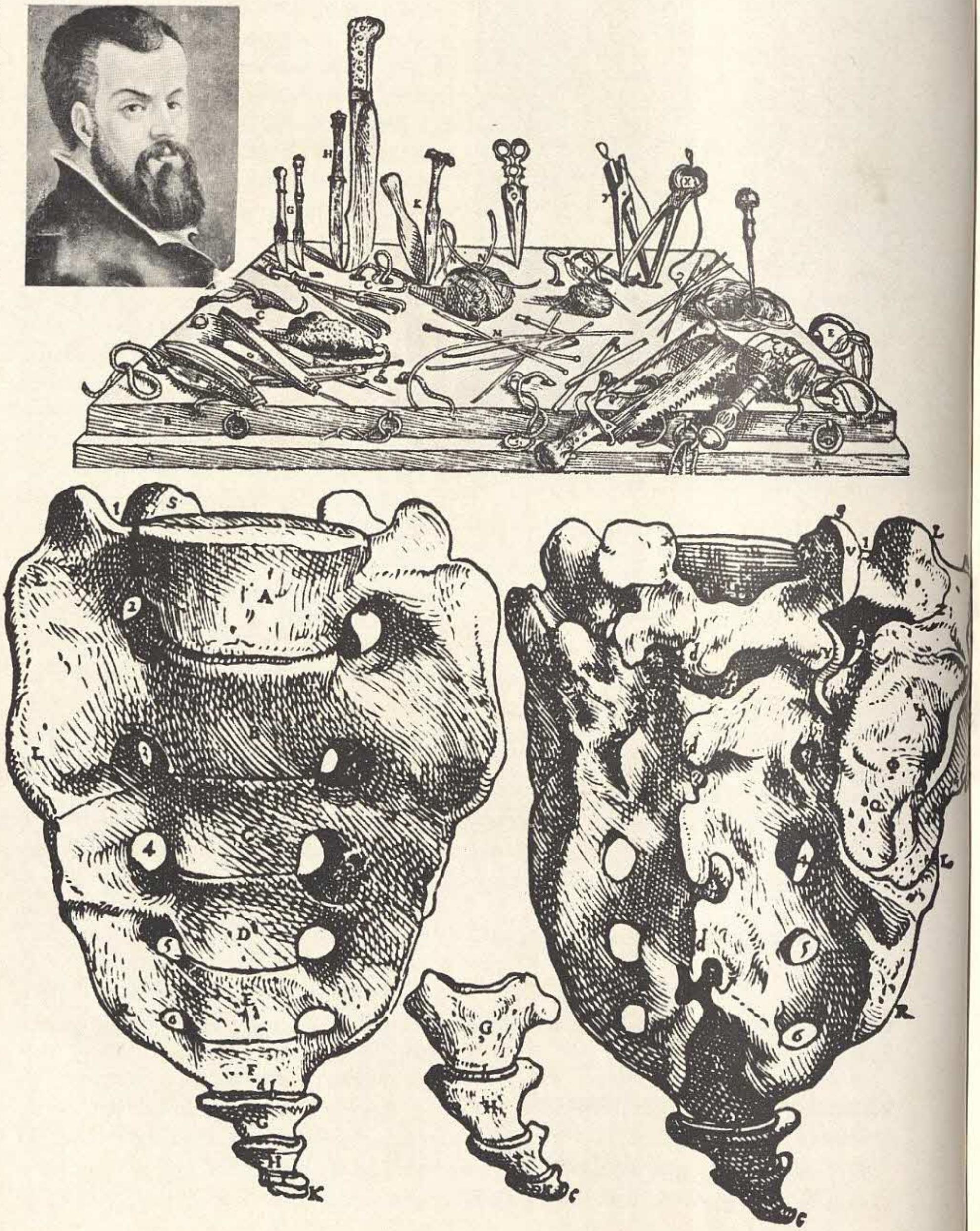
Vesalius was born in Brussels, the son of a court pharmacist to Charles V, emperor of Germany. In 1537 he received medical degrees from both Louvain and the University of Padua in Italy, where he became professor of anatomy and surgery. Because the authorities were quite liberal in allowing human dissections, he chose to live in Italy, also teaching at Pisa and Bologna. In his work, Vesalius personally performed dissections for his students, rather than allowing assistants to dissect the bodies.

His *Tabulae Anatomicae Sex*, published in 1538, marked a milestone in anatomical history. It consisted of six large drawings by Jan van Calcar, a pupil of Titian. The nomenclature introduced by Vesalius in this work formed the basis for modern anatomical terminology.

In 1543 he published his masterpiece, *De Humani Corporis Fabrica*, in seven volumes. These beautifully illustrated books were the first accurate works on human anatomy and won lasting fame for Vesalius. At the time of its publication Vesalius was still under thirty years of age. As a result, his reputation grew, and he was appointed court physician to Charles V and later to Philip II of Spain.

Fame, however, also brought misfortune to Vesalius. Because of his dissections of the human body, he was accused

Among the illustrations that appeared in Andreas Vesalius' book *De Humani Corporis Fabrica* (1543) was one representing the anatomist's table with the instruments used in dissections. Another plate showed parts of vertebrae, the sacrum, and the coccyx.



of heresy by the Inquisition and sentenced to death. His connections with royalty saved him from the ultimate penalty, and his sentence was commuted conditional upon his making a pilgrimage to the Holy Land. On the way back his ship was wrecked, and he drowned.

VIETA, FRANÇOIS (1540–1603)

The French mathematician François Vieta made basic contributions to algebraic geometry and trigonometry. As the first to use letters to symbolize unknowns and constants in algebraic equations, he was responsible for the first systematic algebraic notation. His other contributions included using Archimede's method for calculating pi through polygons of up to 393,216 sides, thereby obtaining a value of pi accurate to ten decimal places, which was the best up to that time. He also introduced many technical terms into the study of algebra, such as *coefficient* and *negative*.

Vieta was born at Fontenay-le-Comte in Poitou. After studying law at Poitiers, he practiced in his native town and then served as councillor of the *parlement* of Brittany. In 1589 he became councillor of the *parlement* at Tours, finally becoming a royal privy councillor. His greatest political service, however, was deciphering the secret code that the armies of Philip II of Spain were using against the French.

Although Vieta pursued mathematics only as a hobby, he accomplished much and published many works. In 1591 his *In artem analyticam isagoge* appeared, followed by *De aequationum recognitione et emendatione* in 1615. The latter work presented his solution of equations of second, third, and fourth degree. His collected works were published as *Opera mathematica* by F. van Schooten at Leiden, the Netherlands, in 1646.

VIGNEAUD, VINCENT DU (1901–)

The U.S. biochemist Vincent du Vigneaud approached the study of amino acids as a detective would probe a difficult case. His investigations into the mysteries of protein structure resulted in discoveries especially valuable to the field of medicine. For his synthesis of the protein hormone oxytocin in 1954, he was awarded the 1955 Nobel Prize in chemistry.

This dramatic achievement came after many years of work on the hormones produced by the posterior lobe of the pituitary gland. Du Vigneaud was particularly interested in the hormone oxytocin, which he broke down into fragments for detailed study. This unusual protein molecule consists of only eight amino acids, whereas the average protein molecule is made of several hundred such acids. Because of its simple structure, oxytocin fit readily into the amino acid chain, the exact order of which Du Vigneaud also devised. While putting the chain together in the order he had deduced, he realized he had synthesized oxytocin.

Du Vigneaud's first major project, completed in the late 1930s, was an exhaustive study of the amino acid methionine and related compounds. He revealed how the body, by shifting a methyl group from compound to compound, sometimes completed the construction of a complicated molecule. As a result of the shifts, the last carbon atom was occasionally slipped in with the active methyl group of the methionine molecule.

He next identified the compound biotin as what had previously been called vitamin H. In 1942 he analyzed its complex two-ring structure and a year later supervised its synthesis by a commercial laboratory.

Du Vigneaud was born in Chicago, Illinois, and received his master's in 1923 from the University of Illinois and his doctorate in 1927 from the University of Rochester in New York. After graduating, he held a number of positions as teaching and research assistant. In 1932 he was named chairman of the department and professor of biochemistry at the George Washington University School of Medicine, Washington, D.C. He remained there for six years and then joined the faculty of the Cornell University Medical College in New York City. In the course of his career he lectured extensively at universities throughout the United States and in England and was honored with numerous degrees and awards for his contributions.

VINCI. See Da Vinci, Leonardo.

VIRCHOW, RUDOLF LUDWIG CARL (1821–1902)

The German pathologist, anthropologist, and statesman Rudolf Virchow is noted in the field of medicine for important contributions to biological thought. Most of his research was in microscopical pathology and histology; and after 1856 he served as director of the Berlin Pathological Institute, which was created as a research center for him.

Virchow discovered and named amyloid, embolism, fibrinogen, hemotoidin, leukemia, myelin, and thrombosis. He also made contributions to the studies of inflammation, trichinosis, and tumors and was active in promoting public health and medical reform.

Rudolf Virchow

Virchow was born at Schivelbein in Pomerania and in 1843 took his medical degree at the University of Berlin. Three years later he was made prosector at Berlin's Charité Hospital and from 1847 also acted as privatdocent at the university. In 1849, when his prosectorship was suspended because he had criticized the government for lack of action during an outbreak of typhus in Upper Silesia, he moved to the University of Würzburg as professor of pathological anatomy. He returned to Berlin, however, in 1856 as professor of pathological anatomy at the university and director of the institute.

In 1861 he was elected to the lower house of the Prussian legislative body, and from 1880 to 1893 he served in the Reichstag as representative from Berlin, where he was also a member of the municipal council. Always interested in anthropology, in 1869 he organized the German Anthropological Society and ten years later accompanied Heinrich Schliemann to the ruins of Troy.

VIRTANEN, ARTTURI ILMARI (1895–)

For his research and discoveries in the fields of agriculture and nutrition, especially for a method of preserving fodder, the Finnish biochemist Artturi Virtanen was awarded the 1945 Nobel Prize in chemistry. In his doctoral thesis Virtanen explained the composition of abietic acid, the principal constituent of rosin. After becoming interested in fodder spoilage and fermentation, he showed that the addition of certain amounts of acids to crops stopped fermentation and ensured a green winter feed. In the interest of better milk production, he conducted extensive experiments in the diets of milch cows.

Virtanen was born in Helsinki and studied chemistry at the university there.

After receiving his doctorate in 1919, he was named chemist of Valio, an organization of dairy cooperatives, becoming its director in 1921. When the larger Biochemical Research Institute in Helsinki was established in 1931, he was named its director. He taught chemistry at the University of Helsinki (1924–1939), biochemistry at the Finland Institute of Technology (1931–1939), and biochemistry at Helsinki (1939–1948). From 1948 to 1963 he served as president of the State Academy of Science and Arts.

VOGT, JOHAN HERMAN LIE (1858–1932)

One who pioneered in the application of physical chemistry to the study of the origin of igneous rocks and ore deposits was the Norwegian geologist and petrologist Johan Vogt. His major studies involved slag; and he attempted to work out, on broad lines, the application of the known laws of solutions to the crystallization of igneous rock magmas.

Vogt was born at Tvedestrand, the son of a physician and, on his mother's side, a nephew of the mathematician Marius Sophus Lie. In 1880 Vogt graduated as a mining engineer from the University of Christiania (later Oslo) and six years later was appointed professor of metallurgy there. From 1912 until his retirement in 1928, he held the chair of mineralogy and geology at the technical high school in Trondheim. His books include *Studier over Slagger* (1884) and *Die Silikatschmelzlösungen* (1903–1904).

VOIT, CARL VON (1831–1908)

The German physiologist Carl von Voit helped lay the foundations for the modern knowledge of metabolism and nutrition. He perfected the technique of balance studies for determining quantitatively the ingestion and excretion of foodstuffs. With a colleague, Max von Pettenkofer, he built a metabolism machine large enough to hold a human being and showed that carbon dioxide production is proportional to the rate of muscular activity. The two men also made the first accurate determination of the energy requirements of man.

Voit was born at Amberg and studied with Justus von Liebig and Friedrich Wöhler. From 1863 to 1908 Voit was professor of physiology at Munich.

VOLTA, ALESSANDRO (1745–1827)

The Italian physicist Alessandro Volta developed the theory of electric current and invented the electric battery, which provided other scientists with the first source of continuous electric current and led to great advances in the field of electricity. In his honor the unit of electromotive force was named the *volt*.

Volta was born at Como, Italy, to an aristocratic family. At first the family thought he was retarded because he did not speak until he was four years old. Educated by learned relatives, however, young Volta soon made up for his slow start in life. At age twenty-four he published his first paper on the phenomenon of electricity, in 1774 he began teaching physics at the Royal School in Como, and in 1779 he was appointed professor of natural philosophy at the University of Padua. His studies of atmospheric electricity led, in 1775, to his invention of the electrophorus, the forerunner of the modern condenser. He also invented an electroscope.

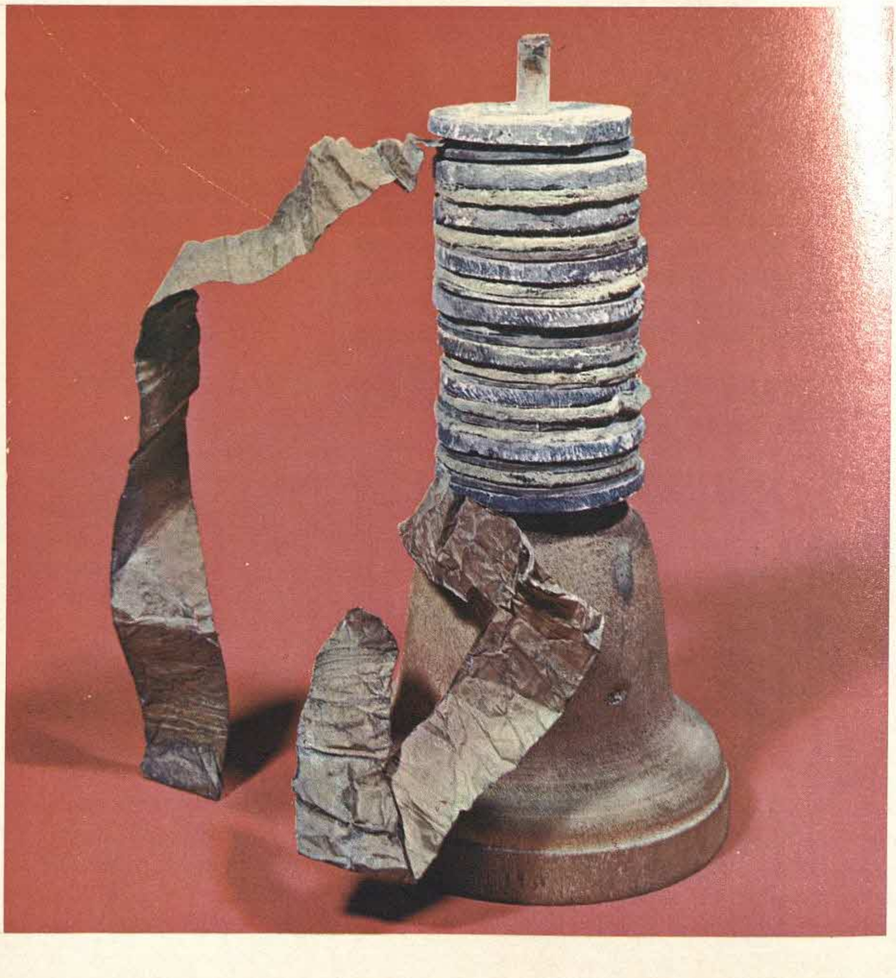
He later became involved in a controversy with Luigi Galvani over the latter's contention that the electric current produced when the legs of a frog made contact between copper and iron was due to a vital force unique to animals, so-called animal electricity. Volta contended that the answer lay in the two types of metal and showed the electricity produced by the frog legs to be identical with that generated from nonliving things.

In 1800 Volta succeeded in generating electricity by connecting two bowls of salt solution with a metal arc, one end of which was copper and the other tin or zinc. That same year he constructed his voltaic pile, the first battery, by alternating disks of copper, zinc, and cardboard that had been soaked in salt water.

Napoleon called upon Volta to demonstrate his new device, and a special medal was struck in Volta's honor. In addition, he was given the title of count and received many other awards, including that of the Legion of Honor and the Copley Medal of the Royal Society.

Alessandro Volta

The first battery constructed by Alessandro Volta consisted of an insulating rod on which were threaded alternating disks of copper, zinc, and cardboard that had been soaked in salt water. As a result of this invention, Volta was created a count and received many awards.



VOLTERRA, VITO (1860–1940)

The modern development of calculus was greatly influenced by the work of the Italian mathematician Vito Volterra, who introduced the concept of the function of a curve, which led to new fields of analysis. He also conducted studies on optics, elasticity, and electromagnetism.

Volterra was born at Ancona and educated at the University of Pisa. In 1883 he became professor of rational mechanics at Pisa, and in 1892 and 1900 he assumed similar positions at the universities of Turin and Rome, respectively. Protesting the oath of loyalty required by the Fascist government, Volterra resigned from the latter school in 1931.

A year earlier his *Theory of Functionals and of Integral and Integro-differential Equations* had been published. It was reissued almost thirty years later, in 1959.

VON BAER. See Baer, Karl Ernst von.

VON BAEYER. See Baeyer, Johann Friedrich Wilhelm Adolf von.

VON BEHRING. See Behring, Ernst Adolf von.

VON BÉKÉSY. See Békésy, Georg von.

VON BRAUN. See Braun, Wernher von.

VON EULER. See Euler, Ulf Svante von.

VON EULER-CHELPIN. See Euler-Chelpin, Hans Karl August Simon von.

VON GESNER. See Gesner, Konrad von.

VON GUERICKE. See Guericke, Otto von.

VON HELMHOLTZ. See Helmholtz, Hermann Ludwig Ferdinand von.

VON HUMBOLDT. See Humboldt, Friedrich Heinrich Alexander von.

VON JAUREGG. See Wagner von Jauregg, Julius.

VON LAUE. See Laue, Max Theodor Felix von.

VON LENARD. See Lenard, Philipp Eduard Anton von.

VON LIEBIG. See Liebig, Baron Justus von.

VON NEUMANN. See Neumann, John von.

VON STRADONITZ. See Kekulé von Stradonitz, Friedrich August.

VON VOIT. See Voit, Carl von.

VON WASSERMANN. See Wassermann, August von.

VON ZEPPELIN. See Zeppelin, Ferdinand, Graf von.

VRIES. See De Vries, Hugo.

WAALS, JOHANNES DIDERIK VAN DER
(1837–1923)

The doctoral dissertation of Johannes van der Waals, submitted when he was a thirty-five-year-old student at the University of Leiden, the Netherlands, contained groundwork for a research project that would lead to his acceptance of the 1910 Nobel Prize in physics. Although Van Der Waals received little formal education before entering the university, his remarkable thesis, *On the Continuity of the Liquid and Gaseous State,* published in 1873, established him as a leader in the European scientific community; it was immediately translated from Dutch into English, French, and German. Four years later he left Leiden, his birthplace, and joined the faculty of the University of Amsterdam as professor of physics. During his thirty-year stay there, he was elected to the Academy of Sciences of Amsterdam and served as its secretary from 1896 to 1912.

Perplexed by the absence of a tenable equation for real gases, Van Der Waals was determined to formulate one. Previously, Robert Boyle and J. A. L. Charles had set forth their "perfect gas equation": ideally, changes in any one of the three variables (pressure, volume, temperature) of any given gas would cause the other variables to adjust themselves so that the constant would remain stable. Unfortunately, this equation does not stand up in actual practice because it assumes that the molecules of a gas are of a negligible size compared with its volume and that they exert no attraction on one another. Taking these erroneous assumptions into consideration, Van Der Waals introduced two more terms, one to account for the molecules' finite size and the other to account for their mutual attraction, and thereby derived from the Boyle-Charles statement and the kinetic theory of gases a new equation that was correct both theoretically and practically.

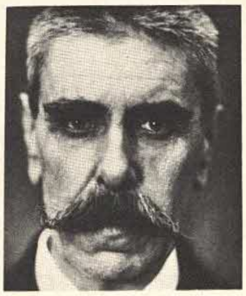
Van Der Waals's ultimate goal was an equation of state that would apply to the gaseous and liquid states of all substances. Eventually, he succeeded in working out an equation valid for any gas and not requiring the new constants, as did his original formula. His new equation was cubic in terms of volume. For a given temperature and pressure, therefore, three possible volumes exist, one of which represents liquid, one gas, and one an unstable state. Van Der Waals's belief that molecules in the liquid and gaseous states are identical and exert identical forces was thus verified.

Serious illness curtailed Van Der Waals's study of physics during the last ten years of his life. It did not prevent him, however, from completing his final project, an elucidation of the law of binary mixtures.

WAGNER VON JAUREGG, JULIUS
(1857–1940)

Two important contributions made by the Austrian psychiatrist Julius Wagner von Jauregg were the treatments he devised for cretinism and for general paresis (syphilitic meningoencephalitis). For his discovery of the therapeutic value of malaria inoculation in the treatment of the latter, he was awarded the 1927 Nobel Prize in medicine or physiology.

Julius Wagner von Jauregg



For thirty-five years Julius Wagner von Jauregg was the head of the University of Vienna's clinic for mental and nervous diseases.

Even in ancient times it had been noted that some patients suffering from mental disease had improved noticeably after contracting a febrile infection. Wagner von Jauregg conceived the idea of deliberately infecting patients suffering from general paresis with a fever-producing disease. General paresis, a form of insanity caused by syphilis germs living in the brain, produced dementia and paralysis. Heat caused by a high fever made it impossible for the germs to exist in the brain. In 1890 he experimented with injections of such substances as tuberculin and staphylococcus vaccine, and in 1917 he began infecting patients with malaria, which was preferable because the infection could be controlled with quinine. The patients showed marked improvement in their paralytic conditions and were offered hope of relief from a disease previously thought incurable.

Earlier in his career he conducted research on the thyroid gland and its relation to cretinism. He found that cretinism could be treated with thyroid gland extract and organized the mass treatment of sufferers in the Styrian Mountains, where the disease was particularly prevalent.

Wagner von Jauregg was born at Wels, Upper Austria. After receiving his medical degree from the University of Vienna in 1880, he stayed on to study and work at its psychiatric clinic. In 1889 he was appointed extraordinary professor of neurology and psychiatry and head of the psychiatric clinic at the University of Graz. He returned to the University of Vienna in 1893 as professor and head of the clinic for mental and nervous diseases.

WAKSMAN, SELMAN ABRAHAM (1888–)

The Russian-born U.S. biochemist Selman Waksman was responsible for discovery of many antibiotics, including streptomycin and neomycin, important substances in fighting infectious diseases. For his discovery of streptomycin, one of the first antibiotics and a medical milestone, he was awarded the 1952 Nobel Prize in physiology or medicine.

Through his research on filamentous bacteria, the actinomycetes, which include many antibiotic-producing organisms, Waksman discovered many new species. Besides streptomycin, the first important agent effective in the treatment of tuberculosis, another important antibiotic discovered was neomycin, useful in treating many infectious diseases of man, animals, and plants. He also devised techniques of microbe culture and ways to isolate and purify antibiotics.

Waksman was born in Priluka, Russia, but emigrated to the United States in 1910, becoming a naturalized citizen in 1916. He attended Rutgers University, New Brunswick, New Jersey, where he received his bachelor's and master's degrees in agriculture in 1915 and 1916, respectively. After taking his doctorate in biochemistry at the University of California in 1918, he returned to Rutgers to do his research and teaching. He advanced to the head of the Department of Microbiology in 1940 and served as director of its Institute of Microbiology from 1949 to 1958, when he became professor emeritus. In addition to his work at Rutgers, Waksman was a marine biologist at the Oceanographic Institute at Woods Hole, Massachusetts, from 1931 to 1942. He also served on a number of governmental committees.

Selman Waksman

He was elected to the National Academy of Sciences in 1942. Among his books are *Streptomycin, Its Nature and Applications* (1949), *Soil Microbiology* (1952), the autobiographical *My Life with the Microbes* (1954), and *The Actinomycetes* (three volumes; 1959–1962).

WALD, GEORGE (1906–)

The U.S. biologist and biochemist George Wald was one of the three men who shared the 1967 Nobel Prize in physiology or medicine. Like the other laureates—Haldan K. Hartline and Ragnar A. Granit—Wald had done research on the mechanisms of sight, and his primary discoveries related to understanding how photoreceptive cells in the retina undergo molecular changes when struck by light. The Nobel citation called him "one of the world's greatest authorities on the biochemistry of perception." (*See* Ragnar Arthur Granit; Haldan Keffer Hartline.)

George Wald

Wald was born in New York City and took his bachelor's degree at New York University in 1927 and his doctorate at Columbia University in 1932. He also studied in Berlin and Heidelberg, Germany; Zürich, Switzerland; and Chicago, Illinois. In 1934 he joined the Harvard University faculty, becoming professor of biology in 1948.

His research demonstrating the basic belief that seeing begins with a chemical reaction earned him many honors, including election to the National Academy of Sciences in 1950 and the Eli Lilly Research Award, the Lasker Award, and the Proctor and Rumford medals. In much of his work he collaborated with his wife, Ruth Hubbard Wald.

WALDEN, PAUL (1863–1957)

The vital phenomenon of optically active compounds now known as the Walden inversion was discovered by the Latvian-born chemist Paul Walden. Simply stated, this refers to an inversion of configuration of one optically active compound into another by the action of certain reagents. He also conducted important research on the electrical properties of solutions.

Walden was born near Riga and educated at the universities of Riga, Leipzig, and Munich. He held successive professorships of chemistry at Riga, St. Petersburg, Moscow, and Rostock and from 1927 to 1928 was a visiting professor at Cornell University, Ithaca, New York, as well. After Rostock was burned in 1942, he became a guest professor at Tübingen.

Among his publications can be found a history of chemistry, *Geschichte der Chemie* (1947). His "Notes from the Life of a Chemist" appeared in an English translation in 1951.

WALLACE, ALFRED RUSSEL (1823–1913)

The English naturalist and explorer Alfred Wallace is best known for his contributions to the theory of the origin of species by natural selection. He is also given credit for laying the basis for the study of animal geography.

Wallace was born at Usk, Monmouthshire, and after his schooling he tried his hand at land surveying, architecture, and teaching. In 1840, however, he became interested in botany and started to collect plants. Within a few years he began to study insects as well; and in 1848 he joined the naturalist Henry W. Bates on a five-year expedition to the Amazon Valley of South America, publishing his observations, *Narrative of Travels on the Amazon and Rio Negro*, in 1853. In the following year he left for the Malay Archipelago, publishing his account of the nine-year expedition, *The Malay Archipelago*, in 1869. While ill of intermittent fever at Ternate, in the Moluccas, in [illegible], he conceived a theory of survival of the fittest, which he immediately sent to the naturalist Charles Darwin in England. Darwin was impressed, recognizing his own as yet unannounced theory in the young stranger's conclusions that had been independently reached. The essay was read, together with an abstract of Darwin's own views, as a joint paper before the Linnean Society in London in July of that same year. Wallace differed with Darwin on certain points and explained his reasoning in *Darwinism*, which he published in 1889. *My Life*, Wallace's autobiography, was published in 1905, and in 1910 the government awarded him the Order of Merit.

Among his other books were *Geographical Distribution of Animals* (1876), *Tropical Nature and Other Essays* (1878), *Island Life* (1880), and *Studies, Scientific and Social* (1900).

WALLACH, OTTO (1847–1931)

Perfume industries all over the world owe a debt of gratitude to the German chemist Otto Wallach for his extraction of aromatic terpenes from essential oils and his clarification of their structure. The Nobel Prize Committee acknowledged his contributions by honoring him in 1910 for his work in the field of pharmaceutical chemistry.

Wallach, who was born in Königsberg, Prussia, attended the University of Berlin and the University of Göttingen, where he received his doctorate in chemistry in 1869. His original plans for an industrial career were abandoned because of ill health, and he chose instead to become an academician. His first position was as assistant to the famous organic chemist Friedrich August Kekulé at the University of Bonn; and in 1876, after six years, he was appointed full professor of chemistry.

Three years later Kekulé's failing health forced Wallach to assume responsibility for teaching his mentor's classes in pharmaceutical chemistry. The prospect excited Wallach, especially because it enabled him to work with natural products for the first time. He was determined to discover their molecular structure, despite Kekulé's discouragement on the grounds that the mixtures the products formed were too complex to be separated. Wallach was undaunted; his first specimens were bottles of essential, or ethereal, oils that had remained unopened in the university's laboratory for fifteen years.

The task required enormous patience and skill, and after twenty-five years Wallach's ambition was realized. From the oils, he had drawn substances called terpenes, the most common of which are camphor and menthol. Previously it was assumed that these were chemically distinct, but Wallach revealed their common carbon skeleton by means of such reagents as hydrogen chloride and hydrogen bromide. Then he tackled the problem of their structures and their mysterious quality of transforming themselves from one to another. In 1895 he discovered a clue to the structure of these baffling materials: the compound alpha-terpineol. It is this compound that renders terpenes basically similar, even though they assume quite different forms.

In addition to aiding the development of modern perfume manufacture, Wallach's findings led to the realization that vitamin A and similar compounds, as well as steroids, such as vitamin D and the sex hormones, are related to the terpenes. He described his discoveries in a series of more than 100 papers and today is credited with launching modern research into the structure of complex natural organic products.

In 1889, after nineteen years, Wallach left Bonn to become director of the Chemical Institute of Göttingen. He stayed there until his retirement in 1915

WALLIS, JOHN (1616–1703)

The contributions of the English mathematician John Wallis led to the growth of the binomial theory and both differential and integral calculus. He refuted long-held erroneous beliefs about motion and gave definite and permanent meaning to such mathematical terms as *force* and *momentum*.

Wallis was born at Ashford, Kent, and, before becoming a priest in 1640, attended Emmanuel College and then Queens' College at Cambridge. His interest in mathematics was stimulated in 1647; and within two years he had mastered the discipline and was appointed Savilian Professor of Geometry at Oxford, a position he held for the rest of his life.

Among his books are *Arithmetica infinitorum* (1655), which influenced Isaac Newton; *Mathesis universalis* (1657); *Mechanica, sive tractatus de motu* (three parts; 1670–1671); and *Treatise of Algebra* (1685).

WALTON, ERNEST THOMAS SINTON (1903–   )

Working with his partner J. D. Cockcroft, at the Cavendish Laboratory in Cambridge, England, the Irish physicist Ernest Walton made great contributions to atomic science. For their extensive work on "the transmutation of atomic nuclei by artificially accelerated atomic particles," the two men shared the 1951 Nobel Prize in physics. (*See* Sir John Douglas Cockcroft.)

Ernest Walton

In collaboration with Cockcroft, Walton bombarded the nucleus of a lithium atom with protons artificially accelerated in a high potential electric field. The disintegration produced a transmutation—helium nuclei instead of lithium nuclei. These experiments were the first in which nuclear disintegration was produced without using radioactive material. The apparatus Walton and Cockcroft devel-

At the Cavendish Laboratory, Cambridge, Ernest Walton achieved nuclear disintegration by artificially accelerated particles.

oped made possible the production of fast atomic particles with energies in the hundreds of thousands of electron volts.

Walton was born at Dungarvan, County Waterford, Ireland, and studied physics and mathematics at the University of Dublin. In 1927 he went to the Cavendish Laboratory to work with Cockcroft. Seven years later he returned to the University of Dublin, where he later became professor and head of the Department of Physics. In 1938 he was awarded the Hughes Medal of the Royal Society.

WARBURG, OTTO HEINRICH (1883–1970)

Among the contributions to science made by the German biochemist Otto Warburg were the discovery of intercellular and yellow enzymes, new ideas about photosynthesis, and advancements in the study of tumor metabolism. For his extensive work, especially his explanation of respiratory enzyme activity, Warburg won the 1931 Nobel Prize in medicine or physiology.

Warburg's research was concentrated on the physical and chemical processes in living cells. He introduced manometric metabolism, developed new methods for studying cancer cells, isolated the first of the yellow enzymes (flavoproteins), and developed a system called the Warburg technique for obtaining thin slices of living cell tissue.

He was born at Freiberg, Germany, the son of a physician. In 1906 he received his doctorate in chemistry at the University of Berlin and in 1911 his medical degree at the University of Heidelberg. Warburg then became a member of the Kaiser Wilhelm (later the Max Planck) Institute for Cell Physiology, being named its director in 1930.

In 1934 Warburg was elected a foreign member of the Royal Society of London. His awards included the Order of Merit of the German Federal Republic in 1952 and the Paul Ehrlich Prize in 1962. He was the author of *The Metabolism of Tumors* (1930), *Hydrogen Transferring Enzymes* (1948), *Heavy Metal Prosthetic Groups and Enzyme Action* (1949), and *New Methods of Cell Physiology* (1962).

WASSERMANN, AUGUST VON
(1866–1925)

One of the most distinguished researchers in the field of immunology was the German bacteriologist August von Wassermann. His greatest scientific triumph was the development of a method for diagnosing syphilis. The syphilitic reaction involved syphilitic antibodies in the patient's blood serum, and the method came to be known as the Wassermann test.

Among his other contributions was his work on immunity to tetanus, diptheria, and the meningococcus. He also established that general paralysis in insane patients was a symptom of the later stages of syphilis.

Wassermann was born at Bamberg, Bavaria, and studied at the universities of Erlangen, Munich, Vienna, and Strasbourg, from which he graduated in 1888. After practicing medicine in Strasbourg, he worked at the Robert Koch Institute in Berlin; and in 1906, the same year in which he developed the Wassermann test, he became director of the institute's Department of Experimental Therapy. In 1913 he was appointed director of the Kaiser Wilhelm Institute at Berlin-Dahlem.

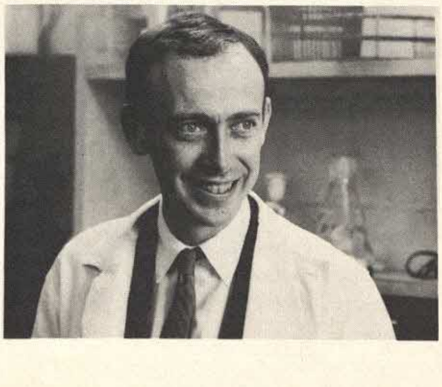
WATSON, JAMES DEWEY (1928–)

One of the contributors to the interpretation of the genetic code was the U.S. biochemist James Watson. For his work with nucleic acids, he shared the 1962 Nobel Prize in medicine or physiology with F. H. C. Crick and M. H. F. Wilkins. He also directed research on cancer-causing viruses. (*See* Francis Harry Compton Crick; Maurice Hugh Frederick Wilkins.)

Early in 1951 he met Wilkins in Naples, Italy, and became acquainted with the data on the x-ray diffraction of DNA (deoxyribonucleic acid) fibers. At Cambridge that same year he met Crick, with whom he began working to solve the puzzle of the structure of the DNA molecule. In 1953 they published their famous hypothesis, proposing that DNA molecules have the form of a double helix.

Watson was born in Chicago, Illinois, and, as a child prodigy, entered the University of Chicago at age fifteen. He studied zoology and went on to take his doctorate at Indiana University, graduating in 1950. Originally he had wanted to become an ornithologist, but while at Indiana University he became interested in biochemistry. In 1950–1951, as a National Research Council fellow at the University of Copenhagen in Denmark, he studied bacterial viruses and then worked with Wilkins and Crick. On his return to the United States in 1953, he became a senior research fellow at the California Institute of Technology, Pasadena, where he investigated the role of RNA (ribonucleic acid) in protein synthesis. Two years later he went back to Cambridge to work with Crick at the Cavendish Laboratory. In 1956 he was appointed assistant professor of biology at Harvard University, becoming associate professor in 1958 and full professor in 1961. A year later he was elected to the National Academy of Sciences.

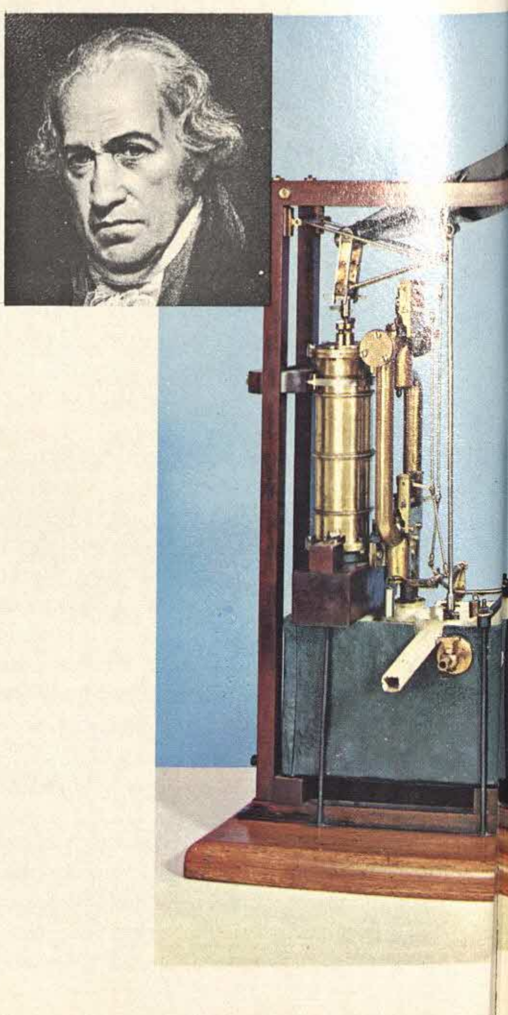
James Watson



WATT, JAMES (1736–1819)

The Industrial Revolution was touched off partly as a result of the work of the Scottish engineer and inventor James Watt, who is generally considered to be the inventor of the modern steam engine. Although he was not the first man to produce such a device, the improvements

By making substantial modifications on an earlier machine of the English engineer Thomas Newcomen, James Watt invented the modern

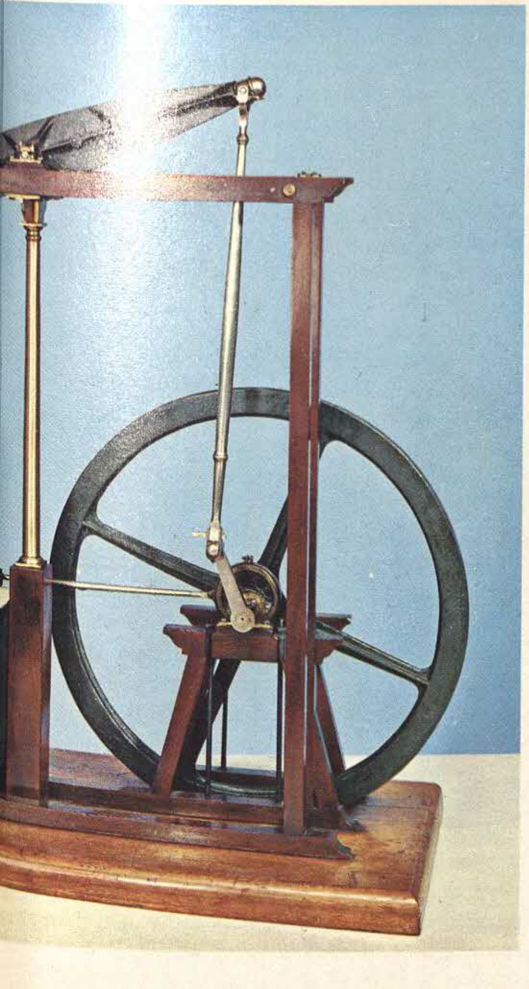


that he added to the earlier engines made steam power a practical way to operate machinery.

Watt was born at Greenock, Scotland. His childhood was an unfortunate one. He had problems with his health; and when he was in his teens, his mother died, and his father, a merchant, ran into troubles in his business. At age nineteen Watt went to London and apprenticed himself to an instrument maker, but after one difficult year he returned home.

In 1757 Watt obtained a position as mathematical instrument maker at the University of Glasgow and while working there became interested in steam engines and in the subject of latent heat. When a Newcomen steam engine was brought to him for repairs in 1764, he began to think of ways to improve the basic model; and the following year, after studying the properties of steam, he invented the modern condensing steam engine. With its two chambers—a condenser to hold exhaust steam and a cylinder that was constantly kept hot—this engine was far more efficient and used less fuel than the Newcomen engine, in which the cylinder, the only chamber, was alternately cooled and heated in the process of creating a vacuum.

condensing steam engine. It consisted of two chambers—a condenser for holding exhaust steam and a cylinder that was always kept hot.



Watt continued to improve his steam engine with the addition of such inventions as the sun-and-planet wheels for converting reciprocal motion into rotary motion and the centrifugal governor, an automatic steam-regulating device. He also invented the steam indicator and, in 1782, the double-action engine. His steam engines were soon adopted to power all sorts of machinery.

With the prosperous manufacturer Matthew Boulton, Watt founded the firm of Boulton and Watt at Birmingham in 1775. For measuring the power of their steam engines, the two men established a unit that they called horsepower. Watt remained a partner in the firm until 1800, when he retired a rich man. The watt, a unit of power, was named in his honor.

WEISMANN, AUGUST (1834–1914)

The German biologist August Weismann is best known for his theory of the continuity of the germ plasm, the basis of much of modern genetics. His early work was in insect embryology, but after 1864 he was concerned mainly with theoretical problems.

Weismann was born at Frankfurt am Main and received his education at the universities of Göttingen and Freiburg. In 1866 he became professor of zoology at the latter university, where he remained until his retirement in 1912.

His most important books were *Studies in the Theories of Descent* (1882), *Essays upon Heredity and Kindred Biological Problems* (two volumes; 1889 and 1892), and *The Germ-Plasm, a Theory of Heredity* (1893).

WELLER, THOMAS HUCKLE (1915–)

With J. F. Enders and F. C. Robbins, the U.S. physician and parasitologist Thomas Weller won the 1954 Nobel Prize in physiology or medicine for applying the technique of tissue culture to the study of the poliomyelitis virus. The accomplishment of the three men facilitated the identification of the virus, made possible its growth in quantity, and led to the development of polio vaccine. Weller is also widely known for isolating the virus of chicken pox and of shingles and proving the common origin of the clinically different diseases. (*See* John Franklin Enders; Frederick Chapman Robbins.)

Weller was born at Ann Arbor, Michigan, and educated at the University of Michigan, where his father was professor of pathology. In the summer of 1938, on a Rockefeller Foundation fellowship, he studied malaria in Florida; and in 1940 he received his doctorate. Early in his career Weller obtained an appointment at Children's Hospital, Boston, Massachusetts, to acquire experience with infectious and parasitic diseases. After World War II, in which he served with the army, studying tropical diseases in Puerto Rico, he finished his hospital training and joined Enders in establishing a research laboratory at Children's Hospital; and there, in 1949, the polio virus was cultivated in tissue culture. From 1949 to 1954, at the same time that he held teaching positions in tropical medicine and tropical public health at Harvard University, he served as assistant director of the laboratory. He was appointed Richard Pearson Strong Professor of Tropical Public Health and chairman of the department at Harvard in 1954, at which time he moved his laboratories to its medical school. Weller was elected to the National Academy of Sciences in 1964.

WELLS, HORACE (1815–1848)

The modern era of painless dentistry was initiated by the U.S. dental surgeon Horace Wells. He was the first dentist to use an anesthetic on patients for the painless extraction of teeth.

In the early 1840s Wells considered the idea that nitrous oxide, or laughing gas, could be used as an anesthetic. In his first experiment with the gas, in 1844, he used himself as the subject. A colleague was persuaded to administer the gas and then extract one of Wells's teeth. The operation was a success. Wells then used nitrous oxide often on his own patients and did much to publicize its anesthetic properties.

Wells was born at Hartford, Vermont, and studied dentistry in Boston, Massachusetts. He set up his practice in Hartford, Connecticut, where the first painless extraction was performed.

After his initial success, however, Wells suffered major setbacks. A demonstration of his anesthetic in Boston was a failure. He then went to Paris, France, but found that the scientists there had a greater interest in ether and chloroform than in nitrous oxide. On his return to the United States he was arrested and charged with acid throwing. While in prison in New York City awaiting trial, he committed suicide.

WERNER, ABRAHAM GOTTLOB (1750–1817)

The German geologist Abraham Werner was founder and leader of the neptunists' school, which proclaimed the aqueous origin of rocks. Although his doctrine has been disproved, he is still noted for showing that the rocks of the Earth follow each other in a certain definite order. His other contributions included the arrangement of geological formations into groups and the systematic classification of minerals.

Werner was born in Upper Lusatia, Saxony, and educated at Bunzlau, Silesia. In 1769 he entered the mining school at Freiberg, where in 1775 he became inspector and teacher.

WERNER, ALFRED (1866–1919)

According to the French-Swiss chemist Alfred Werner, the idea of coordination compounds woke him from a sound sleep early one morning in 1891; and by late afternoon the same day, he had worked out the essential features of a theory responsible for the rapid development of inorganic chemistry. Twenty-two years later, in 1913, he won the Nobel Prize in chemistry. The theory simplified the classification of complex inorganic compounds; revealed unsuspected cases of isomerism, including compounds the optical activity of which is due to elements other than carbon; and proved of value in such diverse fields as mineralogy and analytical chemistry.

Werner's major contribution was to broaden the understanding of chemical structure by demonstrating that the structural relationships between atoms need not be restricted to ordinary valence bonds. The unique aspect of the theory was its deemphasis of the role of these bonds; Werner maintained instead that atoms or groups of atoms are distributed about a central atom as a result of fixed geometric principles. Another name for these coordination bonds is secondary valence. Many years later Linus Pauling, among others, combined Werner's theory with the original valence idea to produce a yet more sophisticated explanation of molecular structure.

As a young boy in Mulhouse, Alsace, France, Werner constructed a laboratory in his parents' barn and by age eighteen had successfully performed several original experiments in chemistry. Classes at the Karlsruhe Technische Hochschule increased his interest in the subject; and when he was twenty, he left France for Switzerland, receiving his doctorate from the University of Zürich four years later. His doctoral dissertation on the spatial arrangement of atoms around a central nitrogen atom was the first of his more than 150 papers on the subject of inorganic chemistry; he also was the author of two textbooks. After studying for some time in Paris, Werner returned to Zürich in 1893, the year he disclosed his new theory, and taught chemistry there until 1919. His students and colleagues considered him an inspiring lecturer, but, unfortunately, ill health forced him to abandon both his experimental work and his teaching when he was only forty-nine.

WERTHEIMER, MAX (1880–1943)

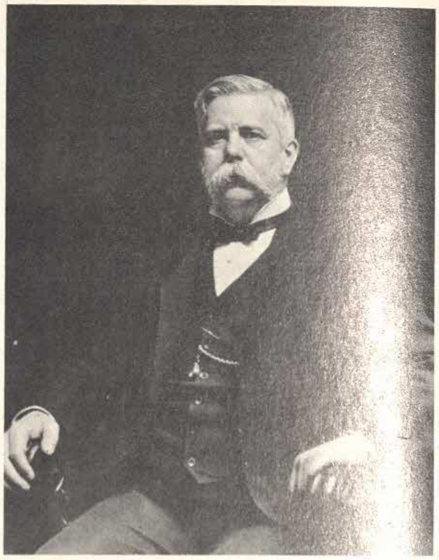
The founder of the Gestalt school of psychology was the German philosopher and psychologist Max Wertheimer. In general, the Gestalt approach concentrated on the structure of the whole, the pattern, and maintained that the parts could not be understood independently of the whole.

The Gestalt school of psychology had its beginning in 1912 when Wertheimer published a paper dealing with apparent motion and applying the Gestalt theory to perception. Wertheimer and his colleagues later applied the Gestalt approach to other areas of psychology, such as problem solving and learning and thinking. The Gestalt school became a major movement and had a tremendous influence on modern psychology.

Wertheimer was born in Prague, Czechoslovakia, and educated in Prague and Berlin, Germany. After obtaining his doctorate from Würzburg in 1904, he taught at Frankfurt and Berlin and in 1929 was appointed professor of psychology at Frankfurt. In 1933 he moved to the United States, where he accepted a professorship at the New School for Social Research in New York City, a post that he held until his death.

WESTINGHOUSE, GEORGE (1846–1914)

The U.S. engineer and manufacturer George Westinghouse invented the air brake, introduced alternating current for power transmission in the United States, pioneered in the utilization of natural gas, and founded one of the world's largest electrical manufacturing companies. During his lifetime he took out more than 400 patents.


George Westinghouse

Westinghouse had an opportunity to develop his inventiveness in Central Bridge, New York, his birthplace, where his father had a shop for manufacturing small steam engines and farm implements. During the American Civil War, Westinghouse served in the Union army and in the navy. After a few months at Union College, Schenectady, New York, he returned home to join his father's works and at age nineteen invented a device for replacing derailed freight cars. In 1869 he patented his air brake and organized the Westinghouse Air Brake Company; and three years later he invented the automatic air brake, which enabled a driver to apply all the individual brakes on coaches simultaneously, thus greatly increasing the safe speed of trains. The system was quickly adopted by railroads in the United States and was eventually accepted in Europe.

While developing a system of railroad signals operated by compressed air and electrical devices, Westinghouse was led to investigate the transmission of high-voltage alternating current. In 1886 he formed the Westinghouse Electric Company. Against opposition that included the weight of electrical wizard Thomas A. Edison, Westinghouse succeeded in obtaining for his company the contract to develop Niagara Falls power on an alternating-current basis. Ironically, Westinghouse was later awarded the Edison Gold Medal of the American Society of Electrical Engineers. In 1955 he was elected to the Hall of Fame for Great Americans.

WHIPPLE, GEORGE HOYT (1878–)

The U.S. physician and educator George Whipple was a winner of the 1934 Nobel Prize in physiology or medicine for his discovery that liver promotes regeneration of hemoglobin, the protein respiratory pigment in red blood cells. He shared the award with G. R. Minot and W. P. Murphy, who established the success of liver diet in the treatment of pernicious anemia. (*See* George Richards Minot; William Parry Murphy.)

Bile pigments, which are formed of hemoglobin, were the primary interest of Whipple when he began to study ways in which the body uses hemoglobin. In

1917 he began a series of experiments in which he bled dogs to induce anemia and then fed them various diets, watching to see how new red blood corpuscles were formed. He found liver to be the most successful diet by far for regeneration of the blood. In other researches Whipple studied tuberculosis and pancreatitis, protein metabolism, and the function of vitamin B_{12}, which proved to be the active agent in liver therapy for pernicious anemia.

Whipple, the son of a physician, was born in Ashland, New Hampshire, and received his bachelor's degree from Yale University in 1900. After taking his medical degree from Johns Hopkins University, Baltimore, Maryland, in 1905, he continued his training in pathology there, becoming associate professor in 1911. He was appointed professor of research medicine in 1914 at the University of California, Berkeley, where he was also named dean of the medical school in 1920. The following year, however, he went to the University of Rochester, New York, as the first dean and organizer of its new medical school. Its innovative design put it under one roof with the university hospital. A longtime trustee of the Rockefeller Institute for Medical Research (now Rockefeller University) in New York City, Whipple was named trustee emeritus in 1960.

Besides the Nobel Prize, Whipple won many other honors. In 1929 he was elected to the National Academy of Sciences, in 1938 to the American Philosophical Society, and in 1941 to the American Academy of Arts and Sciences. He received the Kovalenko Medal of the National Academy of Sciences in 1962 and the Distinguished Federal Civilian Service Award in 1963.

WHITEHEAD, ALFRED NORTH
(1861–1947)

The British-U.S. philosopher and mathematician Alfred North Whitehead made important contributions to modern logic and influenced the development of symbolic logic. He was coauthor with the distinguished philosopher-mathematician Bertrand Russell of the three-volume *Principia Mathematica* (1910–1913), which attempted to establish a definitive system of mathematics based on symbolic logic. About twenty years later, however, the Austrian-U.S. mathematician Kurt Gödel demonstrated the impossibility of creating any such "definitive" system and showed that each system was relative within its own terms. The work of Russell and Whitehead remained important, though, for establishing, in the minds of many mathematicians, serious links between symbolic logic and mathematics.

Whitehead was born at Ramsgate, Kent, and studied mathematics at Cambridge University, graduating in 1884. He became a fellow of Trinity College, Cambridge, and then taught mathematics and served as dean of science at University College, University of London. In 1924 he moved to the United States and became professor of philosophy at Harvard University, where he remained for the rest of his life.

In *The Concept of Nature* (1920) Whitehead examined the basic concepts of modern natural sciences. His other books include *Science and the Modern World* (1925) and *The Function of Reason* (1929).

WHITNEY, ELI (1765–1825)

Although he is best known for inventing the cotton gin, Eli Whitney, U.S. mechanical genius, made perhaps a greater contribution by pioneering the manufacture of interchangeable parts and utilizing the principle of division of labor. He was the first to apply these mass production methods in the United States.

Whitney showed a mechanical bent early in life. By the time he was fifteen years of age, he was manufacturing nails in a small metalworking shop attached to his father's farm in Westboro, Massachusetts, where he had been born. Visiting in Savannah, Georgia, after graduation from Yale University in 1792, Whitney learned of the need for a machine that could separate the short staple upland cotton from its seeds. Within a few weeks he had produced a hand-operated model, and by April 1793 he had built a machine that could clean fifty pounds of cotton fibers in a day. The gin (short for *engine*) consisted of a wooden cylinder encircled by rows of spikes set a half inch apart and extending between the bars of a grid that prevented the seeds from passing through. The lint was pulled through the revolving spikes, which were cleaned by a revolving brush, and the seeds fell into a separate compartment.

Eli Whitney

A patent was granted on March 14, 1794; and Whitney, with his partner, Phineas Miller, began making cotton gins at New Haven, Connecticut. They were so simple and easy to copy that Whitney spent the profits prosecuting infringements on his patent. Although the validity of his patent was settled in 1807, Whitney had become disgusted with the struggle and had opened a musket factory near New Haven in 1798. He secured profitable government contracts by demonstrating the advantages of interchangeable parts in firearms. Whitney became a charter member of the Hall of Fame for Great Americans in 1900.

WIELAND, HEINRICH OTTO (1877–1957)

The German chemist Heinrich Wieland, specializing in the study of steroids, received the 1927 Nobel Prize in chemistry for deducing the structure of the sterol skeleton. Although his deduction was later found faulty, and major revisions were necessary to correct it, Wieland's research was not in vain; his work with bile acids revealed that they are related to one another and to the sterol cholesterol. These findings cast light on the importance of such steroid-related quantities as vitamin D and the hormones controlling sexual development and reproduction.

Much of Wieland's work on steroids was completed during the latter half of his first appointment at the University of Munich (1901–1917). When he returned in 1925, he and his students pursued such diverse subjects as the lobelia alkaloids, butterfly-wing pigments, and phalloidine, a toadstool poison. When he did turn his attention back to the sterol skeleton, he derived the structure that brought him the Nobel Prize.

Wieland's name is often associated with that of Otto Warburg because of the debate that raged between the two on the subject of dehydrogenation. Both men were interested in the oxidations occurring within living tissue. On the basis of extensive experimentation, Wieland held that dehydrogenation, the two-at-a-time removal of atoms from foodstuffs, was the most critical reaction. Warburg, on the other hand, insisted that the addition of oxygen was the more crucial occurrence and maintained that this was catalyzed by enzymes containing iron atoms; Wieland believed that dehydrogenation was also enzymatically catalyzed. Actually, time proved them both correct in their convictions. The controversy provoked an exchange of knowledge vital to understanding the respiratory chain in tissues. The fields of physiology, biochemistry, and medicine benefited especially from their explanation of how energy is produced when the body slowly converts organic molecules to water and carbon dioxide.

Wieland, a native of Pforzheim, Germany, followed in the footsteps of his chemist father, just as his own son Theodor would one day emulate his father by excelling in the field of organic chemistry. He attended universities in Berlin and Stuttgart before receiving his doctorate degree from the University of Munich in 1901. Upon graduation he accepted an assistantship there and remained on the faculty until 1917, when he began teaching at the Munich Technishe Hochschule. Four years later he became professor at the University of Freiburg, and in 1925 he returned to Munich, where he taught chemistry until 1953. At the time of his retirement he was also director of the school's Chemical Institute. Adolf Hitler's rise to power appalled Wieland, and he spoke openly against the dictates of nazism. Despite his opposition, however, he was not persecuted.

WIEN, WILHELM (1864–1928)

The German physicist Wilhelm Wien formulated three laws of radiation that bear his name. He received the 1911 Nobel Prize in physics for his most familiar contribution, Wien's displacement law. A highly specialized area of physics called blackbody radiation was Wien's particular interest; it was his conclusion concerning the wavelength at which maximum energy is radiated that earned him the Nobel honor.

The term *blackbody radiation* refers to that body that, because of its absence of color, absorbs all wavelengths and that when heated radiates all wavelengths. Wien concerned himself with the nature, as well as the amount, of radiation involved. He constructed an enclosed, heated chamber with a small hole in it and observed that light of any wavelength entering the hole was absorbed, not reflected, within. The hole, therefore, should emit blackbody radiation of all wavelengths. In 1893 Wien demonstrated that radiation wavelengths proceeding from the blackbody reach a peak at an intermediate level and that the length of this wave varies inversely according to temperature. This variation of peak wavelength with temperature is called Wien's displacement law.

Spurred on by his findings, Wien next attempted an equation describing the distribution of all wavelengths in blackbody radiation for all temperatures. This time, however, he was not so successful; but he did pave the way for the eventual formulation of the quantum theory, which would affect the entire field of physics in the early twentieth century. In 1896 he devised an equation applicable to the observed distribution of short wavelength radiation.

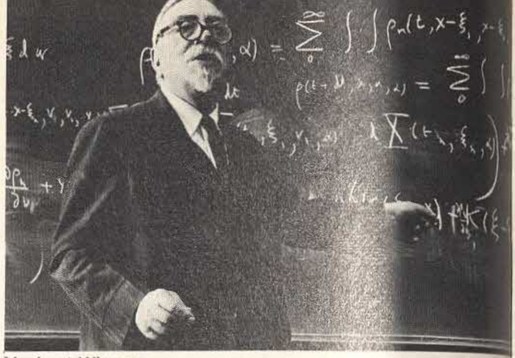
Wien was born in Gaffken, East Prussia, the son of a wealthy landowner. His education, which included study at the universities of Göttingen, Heidelberg, and Berlin, was interrupted in 1886 by the illness of his father. He was forced to take over his family's estate for four years before resuming his career. His first academic position was an assistantship at Berlin's Physicotechnical Institute, his second a teaching appointment in 1896 at the Aachen Technical High School. He remained there for three years and in 1899 went to the University of Giessen, in 1900 to the University of Würzburg, and in 1920 to the University of Munich, where he remained.

Among the wide variety of subjects that attracted Wien's scholarship were hydrodynamics, discharge through rarified gases, and cathode-, x-, and positive-ray measurement. In addition to teaching and experimentation, he edited the *Annals of Physics* from 1906 to 1928.

WIENER, NORBERT (1894–1964)

The U.S. mathematician Norbert Wiener popularized the term *cybernetics* and made important contributions to automation and the development of decision-making devices. He also made valuable additions to the understanding of stochastic, or random, processes and harmonic analysis.

Wiener was born at Columbia, Missouri, the son of a professor of Slavonic languages. He had learned to read and write by the age of three, and at eighteen completed his doctorate at Harvard University. From 1919 until 1960, when he retired as professor, he taught at the Massachusetts Institute of Technology, Cambridge. His books include *The Fourier Integral* (1933), *Cybernetics* (1948), *The Human Use of Human Beings* (1950), *Ex-Prodigy* (1953), *Non-Linear Problems in Random Theory* (1958), and *God and Golem, Inc.* (1964).



Norbert Wiener

WIGNER, EUGENE PAUL (1902–)

The Hungarian-born U.S. theoretical physicist Eugene Wigner did outstanding work in many areas of physics but most notably in mathematical and nuclear physics. Along with Johannes Jensen and Maria Goeppert Mayer, he was awarded the 1963 Nobel Prize in physics "for systematically improving and extending the methods of quantum mechanics and applying them widely." Wigner studied nuclear binding and was interested in symmetry principles as they applied to the regularities exhibited in atomic and molecular spectra. He was one of the first scientists to work on the spectroscopic levels that could be expected from the nuclear shell model proposed independently by Jensen and Mayer. (*See* Johannes Hans Daniel Jensen; Maria Goeppert Mayer.)

Wigner worked on the theory of neutron absorption (important in the technology of nuclear reactors), the theory of conservation of parity, the theory of relativistic wave equations, and the theories of the cohesion of metals. He also applied mathematical group theory to the energy levels of certain atomic nuclei.

Wigner was born in Budapest and was educated as a chemical engineer. After receiving his doctorate from the Technische Hochschule in Berlin, Germany, in 1925, he taught physics at Berlin from 1926 to 1927 and then at the University of Göttingen for a year. In 1928 he returned to Berlin, and in 1930 he moved to the United States, where he accepted a teaching position at Princeton University, in New Jersey. He became a U.S. citizen in 1937 and was appointed professor of mathematical physics at Princeton in 1938.

During World War II, Wigner concerned himself with problems surrounding the production of atomic energy and was influential in convincing the U.S. government of the need for an atomic bomb. He conducted his research for the Manhattan Project at the metallurgical laboratory of the University of Chicago, working on the development and design of the nuclear reactors there and at Hanford, Washington. In 1946–1947 he served as director of research and development at the Clinton Laboratories at Oak Ridge, Tennessee. He was a member of the General Advisory Committee of the U.S. Atomic Energy Commission from 1952 to 1957.

Wigner was elected to the National Academy of Sciences in 1945. The following year he was awarded the U.S. Medal for Merit, in 1958 the U.S. Atomic Energy Commission's Enrico Fermi Prize, and in 1960 the Atoms for Peace Award.

WILKINS, MAURICE HUGH FREDERICK (1916–)

As one of the scientists who worked on the development of the atomic bomb, the British biophysicist Maurice Wilkins developed a profound dislike for nuclear physics and so turned his attention to biology and the life sciences. His work on the x-ray diffraction of the DNA (deoxyribonucleic acid) molecule earned him the 1962 Nobel Prize in medicine or physiology along with F. H. C. Crick and J. D. Watson. (*See* Francis Harry Compton Crick; James Dewey Watson.)

By extending the x-ray diffraction work begun by Max von Laue and the Braggs—William Henry and William Lawrence—Wilkins obtained data on the structure of the DNA molecule. He found that the molecule has a helical form and succeeded in measuring the approximate diameter of the helix. His work on DNA was augmented by that of Crick and Watson. Wilkins also applied x-ray techniques to the study of RNA (ribonucleic acid).

Wilkins was born at Pongaroa, New Zealand, and emigrated to England when he was six years old. He studied physics at St. John's College, Cambridge, and received his doctorate in physics from Birmingham University in 1940. During World War II he worked at the University of California on the separation of uranium isotopes for the atomic bomb. In 1945 he became involved in a biophysics project at St. Andrew's University in Scotland. Later he worked at King's College in London and then with the Medical Research Council Biophysics Research Unit. His other biophysical work was on the genetic effects of ultrasonics and on microscopic and spectrophotometric studies of nucleic acids.

WILLIS, THOMAS (1621–1675)

The English anatomist and physician Thomas Willis was one of the first scientists to study diabetes. His written work on the subject, appearing originally as a chapter of his *Pharmaceutice rationalis—Shewing the Signs, Causes and Cures of Most Distempers* (1674), was the first major treatise on diabetes to be translated from Latin into English. He described such symptoms of diabetes mellitus as increased thirst and urination.

As important as his work on diabetes, if not more so, was his research on the anatomy of the brain. In his major work covering this area, *Cerebri Anatome Nervorumque descriptio et usus,* which was published in 1664, Willis described the eleventh cranial nerve, as well as the ring of arteries that he had discovered at the base of the brain and now known as the circle of Willis. He was also the first scientist to describe general paralysis of the insane, myasthenia gravis, and puerperal fever.

Willis, the son of a wealthy landowner, was born at Great Bedwin, Wiltshire. After graduating from Christ Church, Oxford, in 1636, he pursued medical studies despite serving with the Royalist forces during the Civil War. He received a bachelor of medicine degree in 1646 and was created a doctor of medicine in 1660, the same year that he was appointed Sedleian Professor at Oxford.

WILLSTÄTTER, RICHARD (1872–1942)

One of the grimmest effects of nazism before and during World War II was the brake it applied to scientific progress. The German-Jewish chemist Richard Willstätter's experience typified the plight of scholars whose work was thwarted and whose lives were endangered by the rise of Adolf Hitler and his anti-Semitic followers. In 1915 Willstätter won the Nobel Prize in chemistry for his studies of natural coloring matters; twenty-four years later he was forced to flee Germany for Switzerland to escape persecution.

Willstätter resigned his teaching post at the University of Munich in 1925 as a protest gesture against burgeoning anti-Semitism. This early retirement was virtually the end of his career as a productive chemist. Fortunately, his most valuable contributions were made when he was a young professor at Zürich's Technishe Hochschule, 1905–1912.

It was there he discovered the constituents of chlorophyll to be two closely related compounds containing magnesium, pyrrole residues, and a long-chain alcohol, phytol. He also determined chlorophyll's relationship to blood pigments. His technique for analyzing the properties of chlorophyll has become the universally accepted method for separating mixtures. He discovered how the magnesium atom is placed in the chlorophyll molecule and pointed out that the iron atom is similarly placed in heme, the colored area of a hemoglobin molecule.

One of Willstätter's last projects was an investigation of enzymes and of catalytic hydrogenation. The process of obtaining glucose from wood is based upon Willstätter's study of the degradation of cellulose. Fermentation was yet another subject he pursued.

Willstätter was born in Karlsruhe, Germany, the son of a textile merchant, and became interested in chemistry as a student at the technical high school in Munich. He attended the University of Munich and wrote a doctoral dissertation in 1894 on the structure of cocaine. After teaching both there and in Zürich, he directed Berlin's Kaiser Wilhelm Institute from 1912 to 1916. He then returned to Munich for nine years before retiring. Willstäter spent the last four years of his life in Switzerland, burdened by grief over the death of his wife and son and at the condition of his homeland.

WILSON, CHARLES THOMSON REES (1869–1959)

While spending the summer of 1894 as a volunteer on the staff of a meteorological station atop Ben Nevis, Great Britain's highest peak, the Scottish physicist Charles Wilson became interested in the nature of clouds. His observations led him to invent, in 1911, the cloud chamber, for which he was awarded the 1927 Nobel Prize in physics. Thanks to his ingenious device, mysteries of the subatomic world were clarified. It proved especially valuable in enabling physicists

The cloud chamber invented by Charles Wilson made it possible to observe particle tracks.

to observe and photograph particle tracks of radioactive substances.

So impressed was Wilson by the magnificent clouds over the Highlands that he attempted to reproduce them artificially in a laboratory by means of the adiabatic expansion of moist air within a container. By lowering the air temperature, this expansion caused the excess moisture to condense as water droplets in the form of a cloud. Meteorologists had previously believed that condensation occurred only if each water droplet within a cloud was formed around a nucleus of dust. Wilson demonstrated, however, that some condensation is possible without dust particles if the clouds are exposed to x-rays and concluded, therefore, that charged atoms, or ions, are the nuclei necessary for condensation to occur. In his cloud chamber the paths of single charged particles showed up as trails of minute water droplets. When the chamber was subjected to a magnetic field, the trails of these charged particles curved in such a way as to indicate whether the charge was negative or positive. Wilson studied the trails for traces of collisions between particles and molecules and for activities during and after such collisions.

Wilson was four years old when he and his widowed mother left their native Glencorse and moved to Manchester, England, where he later entered Owens College intending to study biology. Instead, however, he pursued physics and went on to take his degree at Cambridge in 1892. After graduation Wilson, who remained at Cambridge for his entire professional career, joined the staff of the Cavendish Laboratory. In 1900, the year he was elected a fellow of the Royal Society, he became a lecturer at Sidney Sussex College; and in 1925 he was named Jacksonian Professor of Natural History, a position he held until his retirement nine years later.

WINDAUS, ADOLF (1876–1959)

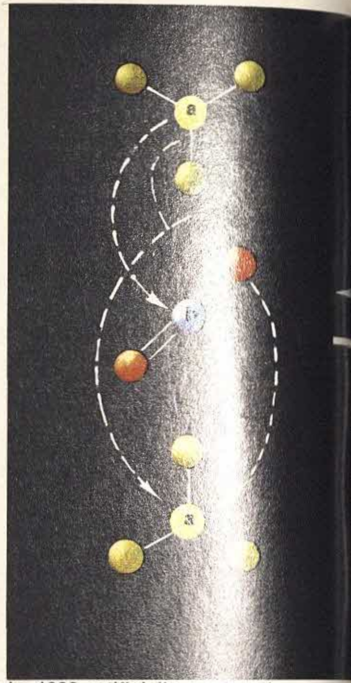
For his discovery that the value of vitamin D, or calciferol, is increased by its exposure to ultraviolet light, the German organic chemist Adolf Windaus received the 1928 Nobel Prize in chemistry. The so-called sunshine vitamin earned its name as a result of Windaus' analysis of its structure; he found that it consists of a steroid molecule in which a bond is broken by the sun's light. The practical applications of this discovery were numerous.

During his career Windaus worked on two significant chemical projects simultaneously. His solution to the puzzle of vitamin D's structure is the most famous. Prior to Windaus, scientists knew there were two ways to prevent rickets in rats: either feed them vitamin D or irradiate their bodies with ultraviolet light. In 1925, with the discovery that irradiation of the rats' food was a sufficient deterrent, it was concluded that the rays converted the cholesterol in the food into vitamin D. Windaus then demonstrated that it was not cholesterol but some unknown minor impurity within the cholesterol that was affected by irradiation. This material was isolated as pure vitamin D in 1936.

Adolf Windaus

An equally important, but less well-known, achievement of Windaus was his breakdown of cholesterol into its various components. First, he observed that substances chemically similar to cholesterol are prevalent among both plants and animals and appear crucial to their biological processes. Later, he successfully converted cholesterol into cholanic acid, from which stem the bile acids. His findings made possible the first successful elucidation of sterol structures. Other contributions attributed to Windaus are the synthesis of histamine and the discovery of sulfur in vitamin B_1.

Windaus was born and reared in Berlin. Although he intended to be a physician and majored in medicine at the University of Freiburg, he changed his mind in the course of his graduate studies. His doctoral dissertation on cholesterol marked the beginning of his lifelong interest in steroids. After receiving his doctorate, he remained at Freiburg for twelve years as professor. From 1913 to 1915 he taught medical chemistry at the University of Innsbruck and then taught at the University of Göttingen until his retirement in 1944.



Friedrich Wöhler in 1828 artificially produced urea; this first laboratory synthesis of a naturally occurring organic compound was of

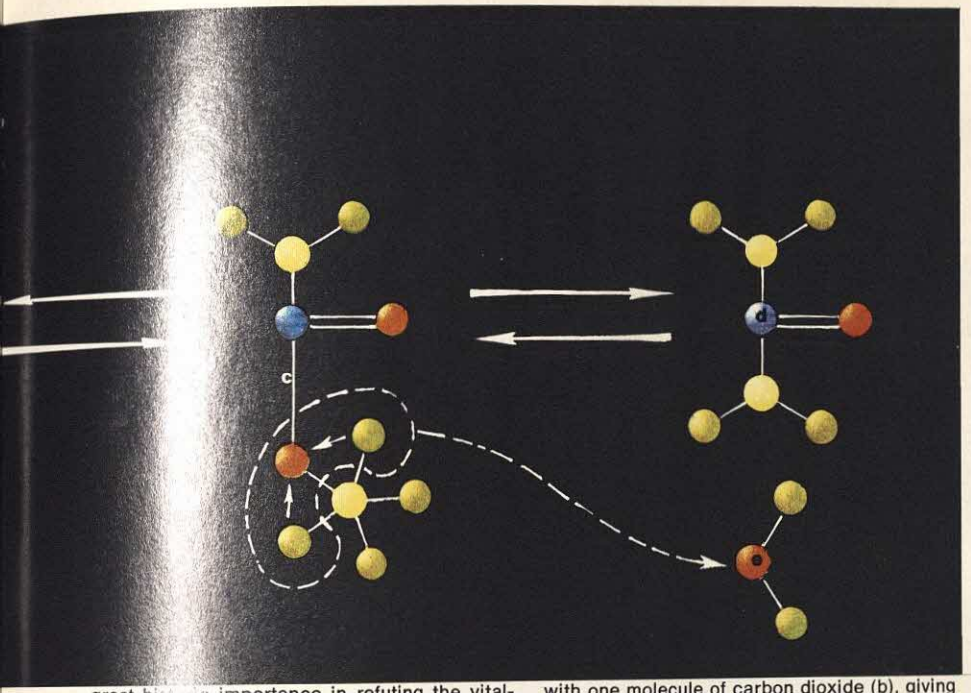
WÖHLER, FRIEDRICH (1800–1882)

Although he was primarily interested in inorganic chemistry, the German chemist Friedrich Wöhler made his greatest discovery in the field of organic chemistry. He was the first chemist to synthesize an organic compound from nonliving material and thereby discredited the vitalistic theory that organic compounds could be obtained only from living organisms.

Wöhler's first researches were in inorganic chemistry. In 1827 he succeeded in isolating metallic aluminum and the following year isolated beryllium. While investigating cyanide compounds in 1828, he heated ammonium cyanate and found that the resulting crystals were urea, a nitrogenous waste product found in urine. This was the first synthesis of an organic compound.

His other outstanding achievements were the isolation of boron and silicon and the discovery of quinone, hydroqui-

Friedrich Wöhler



great historic importance in refuting the vitalism doctrine. In the commercial manufacture of urea, two molecules of ammonia (a) react with one molecule of carbon dioxide (b), giving way to ammonium carbonate (c), which then divides into urea (d) and water (e).

none, and quinhyrone. He also discovered calcium carbide, from which he prepared acetylene, and devised the modern method for preparing phosphorus and also a process for manufacturing nickel. With his friend Justus von Liebig, he investigated the properties of the oil of bitter almonds (benzaldehyde). In the course of this work they traced the radical benzoyl through various chemical processes and found that this group of atoms, or compound radical, stayed intact. The concept of compound radicals was vital to the progress of organic chemistry.

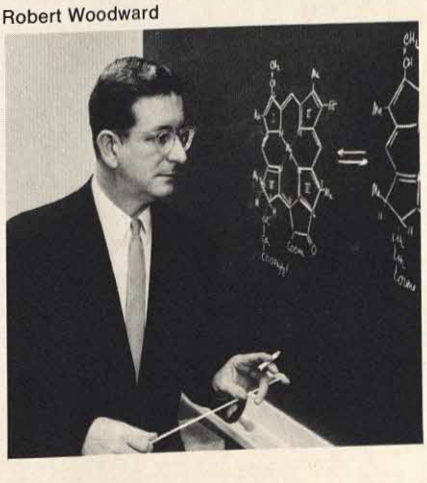
Wöhler was born at Eschersheim, near Frankfurt am Main, and educated at the universities of Marburg and Heidelberg. At the latter school, he worked in the laboratory of Leopold Gmelin, professor of medicine and chemistry and discoverer of potassium ferricyanide (hence also called Gmelin's salt). Wöhler was so knowledgeable that Gmelin advised him not to attend the lectures in chemistry, since they would be a waste of time for him. Pursuing his ambition to become a physician, Wöhler in 1823 received his degree in medicine and surgery; but he was persuaded by Gmelin to devote himself to chemistry instead. He therefore went to Sweden to study with the chemist Jöns Jacob Berzelius. After a year Wöhler returned to Germany and taught at technical schools in Berlin and Kassel before being appointed professor of chemistry at the University of Göttingen in 1836. There he remained for the rest of his life, bringing the department to a high rank. He was not only an inspiring teacher but also a prolific author.

WOODWARD, ROBERT BURNS (1917–)

For his success in synthesizing complicated organic compounds, the U.S. scientist Robert Woodward was awarded the 1965 Nobel Prize in chemistry. His major achievement was successfully bringing about the synthesis of chlorophyll four years earlier.

While still in his twenties, Woodward synthesized cholesterol, cortisone, and strychnine. He also illustrated the difference in structure between chlorophyll, the green matter in plants, and hemoglobin, its counterpart in the red blood cells of vertebrate animals; achieved the successful syntheses of sterols, substances important in human metabolism; and produced three-dimensional models of antibiotic compounds.

Robert Woodward



Woodward was born in Boston, Massachusetts, and demonstrated his ability in chemistry while yet in high school at North Quincy. At sixteen years of age, he went to the Massachusetts Institute of Technology, Cambridge, receiving his bachelor's degree three years later and his doctorate a year after that. He remained at Harvard, becoming Morris Loeb Professor of Chemistry in 1953 and Donner Professor of Science in 1960.

For his contributions to science, he received many honors besides the Nobel Prize. In 1935 he was elected to the National Academy of Sciences, and in 1964 he was awarded the National Medal of Science.

WRAY. See Ray, John.

WRIGHT, SEWALL (1889–)

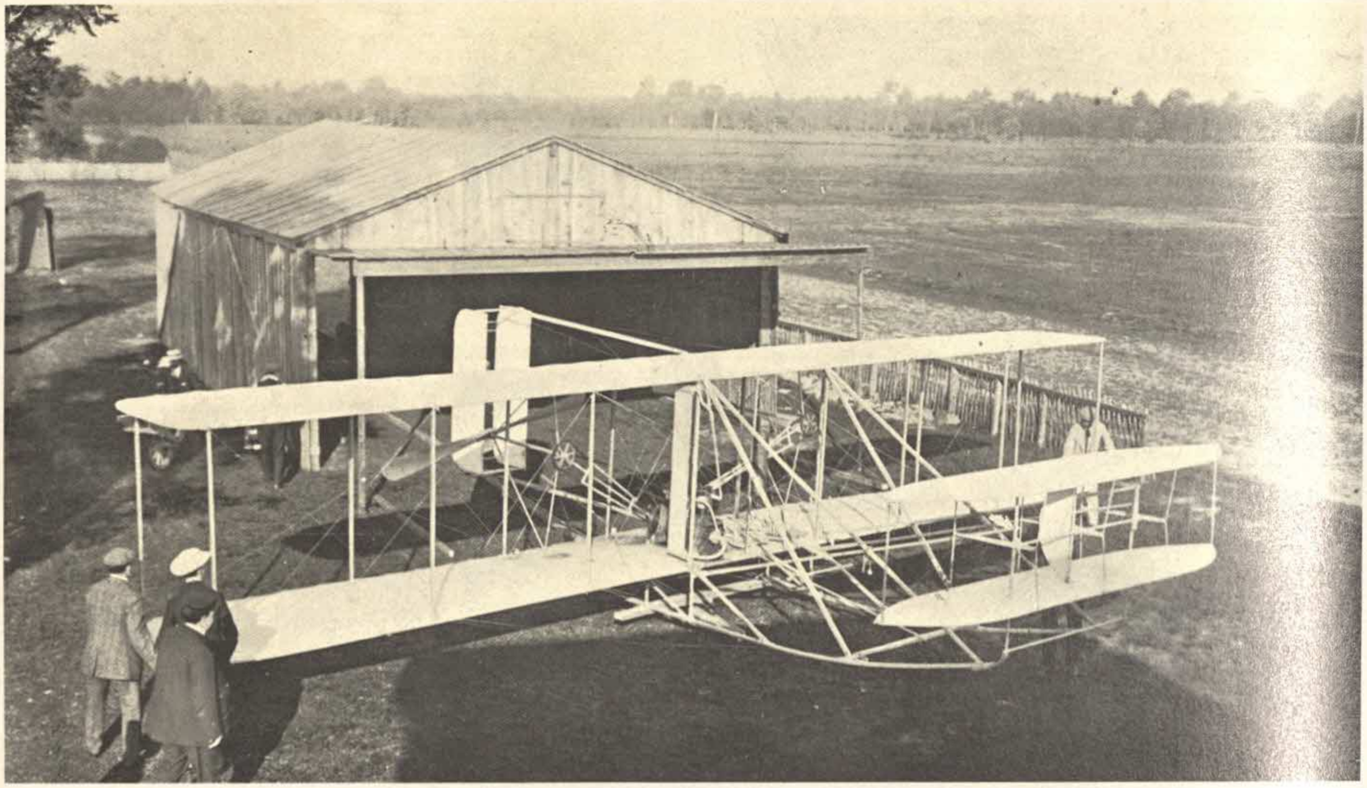
The U.S. geneticist Sewall Wright's best-known research was on the consequences of Mendelian heredity in populations and on experimental physiological genetics of Caviidae. He used a mathematical theory of genetics to find out that evolutionary changes can occur by mathematical chance, as well as by mutation and natural selection.

Wright was born at Melrose, Massachusetts, the son of a mathematics teacher, and studied at Lombard College in Galesburg, Illinois, and the University of Illinois at Urbana before taking his doctorate at Harvard University in 1915. From then until 1924 he was in charge of animal-breeding investigations for the U.S. Department of Agriculture; from 1925 to 1954 he taught zoology at the University of Chicago; and from 1955 until he retired in 1960, he taught genetics at the University of Wisconsin at Madison.

Wright became a member of the National Academy of Sciences in 1934 and received its Elliot Medal in 1945 and the Kimber Genetics Award in 1952. In 1963 he was made a foreign member of the Royal Society of London.

WRIGHT, WILBUR (1867–1912) and ORVILLE (1871–1948)

On December 17, 1903, the age of aviation was born as a result of the work of the two U.S. inventors Wilbur and Orville Wright. On that day the two brothers launched the first successful flight by man in a machine that could lift itself off the



Despite its primitive appearance, the Wright brothers' first powered airplane, *The Flyer*, possessed all the characteristics necessary for a controlled flight, such as vertical and rudders and chain-driven pusher propellers. It was guided by the pilot in a prone position.

Orville and Wilbur Wright

ground and propel itself through the air.

Wilbur Wright was born at Millville, Indiana, and Orville at Dayton, Ohio. Their father was a pastor in a United Brethren church. The formal education of the two brothers was limited to high school; however, they were both mechanically inclined. They designed a newspaper-folding machine, built a press, and for several years published their own newspaper, the *West End News*. Then they opened a bicycle repair shop in Dayton.

In 1896, after reading about the glider flights of Otto Lilienthal, they became interested in the sport of gliding; but they rejected his system of shifting the center of gravity to achieve flight control and instead experimented with the use of ailerons. They built their first glider in 1900, and the following year constructed a wind tunnel in which they tested more than 200 models of gliders. Their third full-sized glider had a movable vertical rudder and adjustable flaps.

During this time they also experimented with building lightweight engines; in fact, they made engines so light that they weighed only seven pounds per horsepower delivered. On their historic flight their plane, *The Flyer,* with its twelve-horsepower, four-cylinder engine, weighed but 750 pounds.

Orville Wright piloted the machine on its first successful flight, which was made at Kitty Hawk, North Carolina. Four flights were made on that day, the longest lasting fifty-nine seconds and covering a distance of 852 feet. The speed of the crude plane was thirty miles per hour. This monumental achievement, however, went almost unnoticed. There were only five people present to witness the event, and there was little coverage in the press.

The Wright brothers continued their experiments. In 1905 Wilbur made a circular flight covering 24¼ miles in thirty-eight minutes and three seconds at Dayton. The following year they patented their plane. Wilbur took the flying machine to France in 1908 and won the Michelin Trophy for a flight that lasted two hours and twenty minutes. That same year the Wrights made a plane for the U.S. War Department; but on a test flight it crashed, killing an officer who had gone along as a passenger. The plane was repaired and the following year passed all the tests.

In 1909 the brothers established the American Wright Company at Dayton and began manufacturing airplanes. Wilbur served as the president of the company until his death, caused by typhoid fever. In 1955 he was memorialized by being elected to the Hall of Fame for Great Americans.

Orville sold his share of the company in 1915 and devoted the rest of his life to research. He became a member of the U.S. Naval Consulting Board and director of the Wright Aeronautical Laboratory at Dayton. The Wright brothers' original airplane was placed in the Smithsonian Institution, Washington, D.C., in 1945, and in 1965 Orville also was elected to the Hall of Fame.

WUNDT, WILHELM (1832–1920)

One of the first men to apply a scientific approach to psychology was the German philosopher, physician, physiologist, and psychologist Wilhelm Wundt. He was also the founder of the content school of psychology, so called because it attempted to describe the content of consciousness. Since Wundt believed that the study of psychology was dependent upon direct experience, his approach to the subject was introspective.

Wundt, the son of a Lutheran pastor, was born at Neckarau, near Mannheim, in Baden, and received his early schooling from private tutors. After obtaining his medical degree from the University of Heidelberg in 1856, he studied for a few months in Berlin and then returned to Heidelberg as a lecturer in physiology. There, in 1862, he began teaching the first course in scientific psychology ever offered. The significance of this was that until that time psychology had been considered to fall entirely within the realm of philosophy. In 1874 he received an appointment at the University of Zürich, where he remained for a year before joining the faculty of the University of Leipzig as professor of philosophy. He established the world's first laboratory for experimental psychology there in 1879 and retained his professorship until his retirement in 1917.

In 1863 Wundt published his lectures on scientific psychology. Approximately ten years later he published his most important work, from a historical view, *Fundamentals of Physiological Psychology*. In 1881 he founded the first journal of psychology. He also wrote extensively on the subjects of philosophy and physiology.

WURTZ, CHARLES ADOLPHE (1817–1884)

The French chemist Charles Wurtz is considered to be the discoverer of the amines and compound ureas. In 1849 he discovered ethylamine; in 1856, the synthesis of ethylene glycol. The previous year he had found that hydrocarbons could be synthesized by the reaction of sodium with alkyl halides. In his honor this chemical action was named the Wurtz reaction. Earlier he did important work on the oxides of phosphorus, discovering phosphorous oxychloride in 1846. He also authored a dictionary of chemistry.

Wurtz was born at Wolfisheim, near Strasbourg, and received his degree from the Strasbourg Medical School in 1843. The following year he went to Paris, where in 1845 he became an assistant at the École de Médecine. There he was professor of organic chemistry and of mineral chemistry and toxicology from 1852 until 1875, when he accepted a professorship in organic chemistry at the Sorbonne. He was honored with foreign membership in the Royal Society in 1864 and was elected to the Académie des Sciences in 1867. Shortly before his death in Paris he served as a senator.

YANG, CHEN NING (1922–   )

The discovery by the Chinese-U.S. physicist Chen Ning Yang of exceptions to the law of the conservation of parity led to many changes in the theory of atomic physics. Yang worked on this project with another Chinese-U.S. physicist, Tsung-Dao Lee; and for their contribution in this area, they were both awarded the 1957 Nobel Prize in physics. (*See* Tsung-Dao Lee.)

Along with Lee, Yang worked on a special type of symmetry law known as the law of the conservation of parity, which states that physical events occur without regard for right or left. According to this law, right and left are interchanged in a sort of mirror effect, represented by the quantum values +1 and −1 and called even and odd parity. Like the law of the conservation of energy, the law of the conservation of parity was assumed to be one of the basic laws of physics.

In 1956 Lee and Yang worked on the problem of the parity of the K-meson, which seemed to contradict the law of the conservation of parity. Their experiments to test the law provided conclusive proof that parity is not conserved in weak interactions, such as the decay of beta particles and other elementary particles.

Chen Ning Yang

Yang was born at Hofei, China, and educated at the National Southwest Associated University at K'un-ming and Tsinghua University. In 1945 he was granted a scholarship and moved to the United States for further study at Columbia University in New York City. Wishing to study with Enrico Fermi, he later enrolled at the University of Chicago, where he was awarded a doctorate in 1948. After graduating, he taught physics there for a year and then became a member of the Institute for Advanced Study at Princeton, New Jersey, being made full professor in 1955.

YERSIN, ALEXANDRE ÉMILE JOHN (1863–1943)

The Swiss bacteriologist Alexandre Yersin won fame as the discoverer of the plague bacillus in 1894 while doing research in Hong Kong. Almost simultaneously, but working independently, Shibasaburo Kitasato made the same discovery. Yersin then undertook the development of a serum for combating the plague, succeeding in 1895.

He was born in Aubonne and educated at Lausanne, Marburg, and Paris. From 1889 to 1890 he worked with Pierre Roux at the Pasteur Institute in Paris on the development of a diphtheria toxin. Yersin then left for the Far East, where he remained for the rest of his life. He did some exploring in China and carried on his research there as well as in what was then French Indochina. Under the auspices of the Chinese government, he founded two branches of the Pasteur Institute, one at Canton and another at Nha Trang. He became director of the institute at Nha Trang. Yersin is also credited with having introduced the rubber tree into Indochina.

YOUNG, ARTHUR (1741–1820)

The English agriculturist and agricultural writer Arthur Young was instrumental in educating British farmers at a time when the agricultural practices of that country were changing from a medieval to a modern system. In addition to his numerous individual publications, he began a journal, *Annals of Agriculture*, in 1784, dedicated to raising the standards of farming.

Young was born in London and in his youth was apprenticed to a merchant. The death of his father and of the merchant, however, made it impossible for him to pursue a career in commerce; and in 1763 he took up farming, but this venture also was unsuccessful. He then turned to writing on agriculture, his first work appearing in 1767, followed by works on a series of tours through Britain and the Continent. In 1793, when the Board of Agriculture was established, Young was appointed secretary.

YOUNG, THOMAS (1773–1829)

The English physician, physicist, and Egyptologist Thomas Young contributed to the development of the wave theory of light and discovered the principle of interference of light. He did important work in other areas of physics and in physiological optics as well. Skilled in languages, he also helped decipher the hieroglyphic inscriptions of the Rosetta Stone.

While still a student he established a reputation for himself with his work on the ciliary muscle and its effect on the accommodation of the eye, the means by which the lens changes shape to focus on objects at varying distances. This work led to his election to the Royal Society in 1794.

Young's other important research on the physiology of the eye included his description and measurement of astigmatism in 1801 and his suggestion that the perception of color is due to three types of nerve structures in the eye that respond to red, green, and violet light, respectively. This theory was later developed by H. L. F. von Helmholtz and became important in color photography and eventually in color television.

In 1801 Thomas Young was appointed professor of natural philosophy at the Royal Institution, where he remained until 1803.

In the area of physics, besides discovering the principle of the interference of light, Young did work on the cohesion of fluids and on the nature of elastic substances. The constant in equations concerning elasticity is known as Young's modulus. He gave the modern scientific meaning to the word *energy*—the property of a substance or system that makes it capable of doing work—and also explained the theory of capillarity.

Thomas Young

Young was born at Milverton, Somerset, England, and educated at Emmanuel College, Cambridge, and at Edinburgh. Three years after receiving his medical degree from Göttingen, Germany, in 1796, he began practicing medicine in London. From 1801 to 1803 he was professor of natural philosophy at the Royal Institution. Not being a successful lecturer, however, he returned to private practice and from 1811 was a physician at St. George's Hospital. He also served as secretary of the Commission on Weights and Measures and foreign secretary of the Royal Society.

YUKAWA, HIDEKI (1907–   )

The Japanse physicist Hideki Yukawa was the founder of the meson theory, one of the most important theories in nuclear physics. For his investigations in theoretical physics, especially his work concerning elementary particles, he won the 1949 Nobel Prize in physics.

In 1935, early in his teaching career, Yukawa developed a new theory of nuclear forces in which he predicted the existence of mesons, or particles with masses between those of the electron and the proton. Two years later the discovery of a type of meson in cosmic rays established the importance of Yukawa's theory. After his work with mesons, he turned to a more sophisticated theory of elementary particles based on his idea of the so-called nonlocal field.

Hideki Yukawa

Yukawa was born in Tokyo, the son of a geology professor. In 1929 he received his bachelor's degree from Kyoto University and lectured there for several years before becoming assistant professor of physics at Osaka University in 1936. He took his doctorate there in 1938, and the following year was named to the post of professor of theoretical physics at Kyoto, where in 1953 he became director of the Research Institute for Fundamental Physics. Meanwhile, he had held two visiting professorships—at the Institute for Advanced Study in Princeton, New Jersey, in 1948 and at Columbia University in New York City from 1949 to 1953. Yukawa was elected a foreign associate of the U.S. National Academy of Sciences in 1949.

ZEEMAN, PIETER (1865–1943)

The Dutch physicist Pieter Zeeman shared the 1902 Nobel Prize in physics with his professor at the University of Leiden, H. A. Lorentz. Their joint contribution to the advancement of spectroscopy was the Zeeman effect, a demonstration of the relationship between light and magnetism. Thanks to Zeeman and Lorentz, astronomers could detect magnetic effects at the sun's surface and details concerning the magnetic fields of stars. (*See* Hendrik Antoon Lorentz.)

While at Leiden, Zeeman began his examination of the effect of a magnetic field on light. He first observed that the lines in the emission spectrum widened slightly when a magnetic field was applied to the light of sodium or lithium flames. Changes in the flames' shape were not responsible for this widening because a similar effect occurred with the absorption spectra. In 1897, the year Zeeman was appointed lecturer at the university, he verified Lorentz' contention that because vibrating electrons produced light, the lines should split, as well as widen. Zeeman's proof of the theory showed that the spectral lines of light in an intense magnetic field split into three components. His effect also confirmed Lorentz' belief that the charged particles of the atom were affected by a magnetic field.

Zeeman, the son of a Lutheran minister, was born in Zonnemaire, the Netherlands, and educated at Leiden. After receiving his doctorate there, he joined the faculty as assistant to Lorentz and stayed there until 1900, when he was appointed professor of physics at the University of Amsterdam. Eight years later he was named director of its Physical Institute. Although his study of magneto-optics at Amsterdam was hindered by poor experimental facilities, he persevered. His most notable achievements there were his propagation of light in moving media and his derivation of nuclear moments from hyperfine spectra. He was elected a foreign member of the Royal Society in 1921 and received its Rumford Medal the following year.

ZEISS, CARL (1816–1888)

The German industrialist Carl Zeiss, who became internationally renowned as a manufacturer of optical instruments, particularly telescopes, was born in Weimar. In 1846 he opened a workshop at Jena to make his instruments. Later he hired Ernst Abbe, professor of physics at the University of Jena, to make certain that his products were technically correct. Eventually Abbe became his partner, and the two men hired the glass chemist Otto Schott, who developed approximately 100 new optical glasses while associated with them.

Abbe was able to make tremendous improvements on previous microscopes. He designed supercorrected immersion objectives that he called apochromatics and also made an improved refractometer to measure light refraction. It was generally thought that Zeiss, Abbe, and Schott had produced the finest, most advanced microscopes that could be made. Later improvements were made, however. The Dutch professor Frits Zernike introduced the phase contrast principle to microscopy and persuaded the Zeiss firm to introduce such equipment in 1935.

After Zeiss's death, Abbe became the sole owner of the firm. He then donated it to the Carl Zeiss Foundation.

In 1945, at the close of World War II, the board of the Zeiss firm, along with approximately 100 of its leading scientists and technical workers, were evacuated from Jena (which was then in East Germany, controlled by the Communists) by the U.S. Army. The Carl Zeiss Foundation was reopened in Heidenheim, West Germany, and the Carl Zeiss factory was newly located at Oberkocke. The Schott glassworks were moved to Mainz.

ZEPPELIN, FERDINAND, GRAF VON (1838–1917)

The world's first airship of rigid design, the dirigible, was engineered by the German inventor Ferdinand, Graf von Zeppelin. Dirigibles came to be commonly known as zeppelins and were the first airships to be powered by engines. Many of them were filled with highly explosive hydrogen gas.

Zeppelin was born at Constance, Baden, and educated in preparation for a military career. While in the United States as an observer in the Union army during the American Civil War, he became interested in balloons capable of carrying men. It wasn't, however, until after his retirement in 1891 with the rank of lieutenant general—long after he had returned to Germany and pursued a military career—that he turned his attention to the development of dirigibles.

His first dirigible, which was a cigar-shaped aluminum structure powered by an internal-combustion engine, was sent into the air on July 2, 1900. It flew at a speed of twenty miles per hour. After building two more experimental models, he formed a company and built five more airships. Before his death at Charlottenburg he saw his zeppelins stage attacks on London during World War I. After the war, dirigibles were manufactured in the United States by the Goodyear-Zeppelin Company. Two of the most famous dirigibles were the *Graf Zeppelin* and the *Hindenburg*.

ZERNIKE, FRITS (1888–1966)

The Dutch physicist Frits Zernike developed an optical method that made possible for the first time microscopic examination of the internal structure of cells without staining them. For this method of phase-contrast microscopy, as well as other outstanding contributions in the field of optics, he received the 1953 Nobel Prize in physics.

Frits Zernike

Zernike's early research involved diffraction gratings and astronomical telescopes. He later published his diffraction theory, including the discovery of the so-called polynomials of the phase-contrast method. The latter method, when applied to microscopy, brought about revolutionary advances in biological and medical research.

Zernike was born in Amsterdam and educated at the University of Amsterdam. After receiving his doctorate in 1915, he joined the Department of Astronomy at the University of Groningen, becoming professor in 1920. He remained there as professor of theoretical and technical physics and theoretical mechanics until his retirement in 1958. Ten years earlier he had been visiting professor for a year at Johns Hopkins University, Baltimore, Maryland. In 1952 he was awarded the Rumford Medal of the Royal Society of London.

ZIEGLER, KARL (1898–)

For devising a low-pressure process that produced a stronger and more heat-resistant polyethylene, Karl Ziegler, German organic chemist, won a share of the 1963 Nobel Prize in chemistry. The co-winner was the Italian chemist Giulio Natta. (*See* Giulio Natta.)

Ziegler's prizewinning work was his discovery in 1953 that substances made by mixing organometallic compounds with compounds of certain heavy metals bring about the fast polymerization of ethylene, at atmospheric pressure, to a linear polymer of high molecular weight. Polymerization is a process by which simple molecules are linked in chains or rings to form giant molecules, or polymers. The Ziegler process resulted in a straight-chain polymer rather than a branched-chain polymer, in which the branches weaken the final product.

After World War II, Ziegler concentrated on organic compounds of aluminum. He demonstrated that ethylene could be added to the aluminum-carbon bond of aluminum trialkyls, permitting the syntheses of higher aluminum trialkyls, from which alcohols for detergents could be obtained. He found also that nickel would catalyze the exchange of groups attached to aluminum by ethylene, thereby liberating higher olefins, and that metal alkyls can be prepared from aluminum trialkyls by electrochemical techniques; the gasoline antiknock additive lead tetraethyl is a leading example.

One day Ziegler and a student, E. Holzkamp, were about to prepare higher aluminum alkyls by heating ethylene and aluminum triethyl. Unexpectedly, they obtained a complete conversion of the ethylene monomer to the dimer, butene-1. Seeking an explanation, they found in the autoclave a trace of colloidal nickel derived from the catalyst used in previous hydrogenation experiments. This event led to the discovery for which Ziegler was cited in the Nobel award. The catalyst derived from aluminum alkyl and titanium tetrachloride formed the basis of nearly all later developments in man-made plastics, rubbers, fibers, and films, which stem from such olefins as ethylene and butadiene.

Ziegler, the son of a minister, was born in Helsa, Germany, and educated at the University of Marburg. After receiving his doctorate in 1923, he remained at Marburg as a lecturer until 1925. Subsequently, he taught at the universities of Frankfurt and Heidelberg, where he became professor in 1927. He left Heidelberg in 1936 to be professor of chemistry and director of the Chemical Institute at the University of Halle. In 1943 he was appointed director of the Kaiser Wilhelm (later the Max Planck) Institute for Coal Research in Mülheim. Beginning in 1947, he served also as honorary professor at the Technical High School in Aachen.

ZIRKEL, FERDINAND (1838–1912)

The German engineer Ferdinand Zirkel was a pioneer in the use of microscopes to study and classify rocks (microscopic petrography). After a visit to England in 1868, he made sections of rocks and studied them according to the techniques he had learned from H. C. Sorby, whom he had met on the trip and who was doing pioneer work with the microscope in connection with geological studies. Zirkel also introduced microscopic petrography to the United States after the geologist Clarence King asked him to describe some rocks collected along its 40th parallel.

Zirkel was born in Bonn, Germany, and trained as a mining engineer. In 1863 he became professor of mineralogy at Lemberg University, and in 1870 he was appointed professor of mineralogy at the University of Leipzig. He retired from teaching and research in 1909.

Zirkel's famous book *Lehrbuch der Petrographie* (1866) was written before he had heard about microscopic petrography. In 1870 he published a book on the characteristics of basalts, dedicating it to Sorby in appreciation for his help. Three years later his book about microscopic petrography, *Mikropische Beschaffenheit der Mineralien und Gesteine*, appeared. In 1876, employing his microscopic techniques, Zirkel wrote the fourth volume of the report of the King survey. After he had gained new knowledge of the microscope as a potent tool, Zirkel rewrote *Lehrbuch* almost completely (three volumes; 1894).

The mineral zirkelite was named in his honor. It consists of a basic hydrous chloride of iron, magnesium, calcium, and aluminum; it is isometric and brittle, with a shiny luster; and when sectioned into very thin segments, it appears to have a brownish or dark red cast. It occurs in Brazil and was first located at Jacupiranga, near São Paulo.

ZSIGMONDY, RICHARD ADOLF (1865–1929)

While employed at the Schott Glassworks in Jena, Germany, the Austrian chemist Richard Zsigmondy investigated submicroscopic water suspensions of gold. His desire to examine more closely these particles, so minute that they remained suspended rather than settling out, led to his invention of the ultramicroscope. For designing this tool and for his ensuing discoveries about colloids, he was awarded the Nobel Prize in chemistry in 1925.

Despite their extremely small size, colloidal particles do scatter light. Zsigmondy reasoned, therefore, that only scattered light would enter a microscope if that microscope were adjusted at right angles to the beam of light shining through a colloidal solution. In 1903, with the help of a physicist, he perfected the ultramicroscope, which made possible the observation of colloid particles as points of light. Although still too small to be seen in detail, they could at least be counted and their movements traced. The ultramicroscope also revealed something of the size and shape of the particles.

Zsigmondy, the son of a Viennese physician, was educated in Germany, where he spent his entire professional career. His interest in colloids stemmed from postgraduate study of glass colors. After receiving his doctorate in organic chemistry from the University of Munich in 1889, he worked as a research assistant in Berlin and Graz for eight years. He was particularly intrigued by the colors resulting from the application of organic solutions of gold to porcelain. Because of his specialized knowledge, he was hired by the glassworks at Jena in 1897, and during the next three years he produced several types of colored glass, including so-called milk glass. Frustrated, however, by his inability to view closely colloidal gold particles, he left the works in 1900 and devoted himself to designing the ultramicroscope. He continued his colloidal research in his private laboratory until 1907, when he joined the faculty of the University of Göttingen as professor of inorganic chemistry.

During his lifetime Zsigmondy was the acknowledged expert on colloidal chemistry. His systematic investigation of colloids as a subdivision of matter greatly advanced man's understanding of smoke, fogs, foams, and films. Biochemistry, bacteriology, and soil physics were the areas of science to benefit most from Zsigmondy's discoveries.

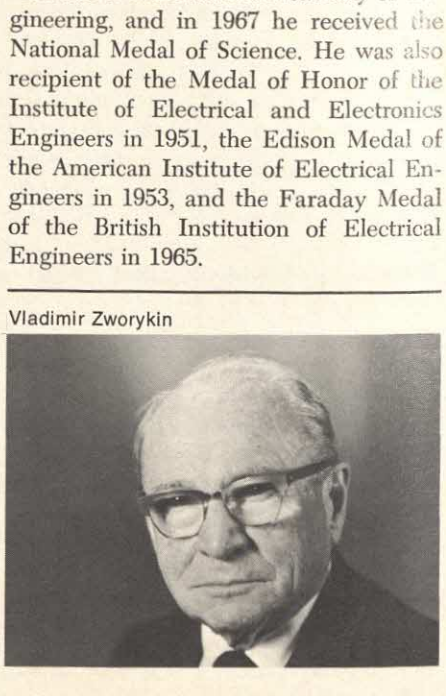
ZWORYKIN, VLADIMIR KOSMA (1889–)

The Russian-born U.S. electronic engineer and inventor Vladimir Zworykin is known as the Father of Television because he invented the iconoscope, the camera tube that made possible the development of the all-electronic television system. During his long career he continued to work on improvements for television, as well as helping develop the electron microscope, the electron multiplier tube, and the electronic vehicle control system.

Zworykin was born at Mourom, Russia, and took a degree at the St. Petersburg Institute of Technology before going on to Paris to take advanced studies at the Collège de France. After World War I he moved to the United States to do research for the Westinghouse Corporation in Pittsburgh, Pennsylvania, and continued his studies at the University of Pittsburgh, receiving his doctorate in 1926. He joined the research staff of RCA (Radio Corporation of America) in 1929 and headed the electronic laboratory at Camden, New Jersey, and later at Princeton, New Jersey. From 1954 to 1962 he was director of the electronics center at the Rockefeller Institute for Medical Research (later Rockefeller University) in New York City.

Zworykin received the 1941 Rumford Medal from the National Academy of Sciences and was elected a member two years later. In 1965 he was elected a member of the National Academy of Engineering, and in 1967 he received the National Medal of Science. He was also recipient of the Medal of Honor of the Institute of Electrical and Electronics Engineers in 1951, the Edison Medal of the American Institute of Electrical Engineers in 1953, and the Faraday Medal of the British Institution of Electrical Engineers in 1965.

Vladimir Zworykin



ALFVÉN, HANNES OLOF GÖSTA (1908–)

A Swedish physicist who pioneered research in the behavior of high-energy conductive gases in magnetic fields, Hannes Alfvén was co-winner of the 1970 Nobel Prize in physics. Sharing the award was the French physicist Louis E. F. Néel. Alfvén was cited for his fundamental contribution and discoveries in magnetohydrodynamics with applications in various parts of plasma physics. (*See* Louis Eugène Félix Néel.)

Magnetohydrodynamics is important in development of controlled thermonuclear reactors and also applies to the thrust for outer space propulsion and to space-vehicle braking upon reentry into the atmosphere. Plasma, sometimes referred to in physics as the fourth state of matter (after the solid, liquid, and ordinary gas states), is an electrically conductive gas composed of neutral and ionized particles and free electrons. An understanding of plasma physics is necessary for explaining the origin of the solar system.

Alfvén was born in Norrköping, Sweden, and educated at the University of Uppsala. As a faculty member of the Royal Institute of Technology in Stockholm, he served successively as professor of electricity (1940–1945), electronics (1945–1963), and plasma physics (1963–1967). Protesting what he considered inadequate funds for research projects on peaceful uses of the hydrogen bomb, Alfvén left Stockholm in 1967. He was offered chairs by the Soviet Union and the United States. After a short stay in Russia, he moved to the United States. He made his peace with the Swedish government shortly thereafter and began teaching six months each year at the University of California in San Diego and six months at the Institute of Technology in Stockholm. In California, Alfvén taught astrophysics to postgraduate students.

One of Alfvén's better-known papers, "On the Origin of the Solar System," was written in 1954. He was elected to the U.S. National Academy of Sciences and other learned bodies and in 1967 was awarded the Gold Medal of the British Royal Astronomical Society.

HOWE, ELIAS (1819–1867)

The sewing machine, which was the first invention that appreciably lightened the work of women in the home, was invented by Elias Howe, a nineteenth-century U.S. machinist. Like other labor-saving devices, it met with early resistance because of the fear of industrial unemployment.

Howe was born at Spencer, Massachusetts, where he took particular interest in the machinery in his father's gristmills and sawmills. At age twelve he was apprenticed for two years in a cotton machine shop in Lowell, Massachusetts; and later he worked for an instrument maker in Boston, Massachusetts. Struck by the fact that every phase of spinning and weaving had been mechanized while family sewing still was done by hand, Howe conceived the idea for a sewing machine and spent five years in its development. By 1845 he had built a machine that sewed 250 stitches per minute. He was granted a patent in the following year.

Elias Howe

A London, England, manufacturer asked Howe to work for him, applying the invention to the making of shoes. Howe accepted and sold the British rights to the manufacturer for a small sum. Before long, however, they quarreled; and Howe returned to the United States, instituting prolonged litigation to protect his patent from widespread piracy. His rights were established in 1854, and for the rest of his life he received royalties on all sewing machines made in the United States. In 1915 Howe was elected to a place in the Hall of Fame for Great Americans.

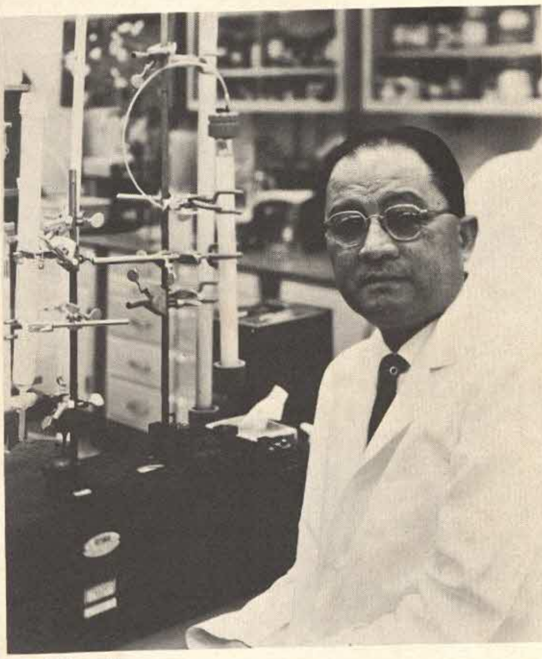
LI, CHOH HAO (1913–)

The Chinese-American biochemist Choh Hao Li was responsible for isolating and synthesizing the human pituitary growth hormone (HGH). Besides directly benefiting victims of pituitary dwarfism, the achievement was expected to provide a tool for research on cancer, heart disease, metabolism, and bone and tissue repair. Before the synthesis of HGH, such treatment and study were hampered by the extremely limited supply of the HGH hormone from the pituitary glands of human cadavers.

After identifying the structure of the HGH molecule in 1966, Li spent four years on the painstaking task of synthesizing the complex molecule, which consists of a chain of 188 amino acids with two loops—one containing six subunits, and the other, ninety-three. During his career of investigation into the pituitary—the master gland that holds the chemical key to nearly all important body functions by controlling the release of hormones by other glands—Li and his associates isolated and purified eight of the pituitary's ten known hormones.

Li was born in Canton, China, the son of an industrialist. He graduated from the University of Nanking in 1933 and two years later went to the United States to study at the University of California at Berkeley. After receiving his doctorate there in 1938, he joined the faculty and served successively as professor of biochemistry, professor of experimental endocrinology, and director of the university's hormone research laboratory in San Francisco.

In 1955 Li became a naturalized U.S. citizen. His many honors and awards from learned societies in North and South America, Europe, and Asia included the Lasker Award for Basic Medical Research in 1962 and the Scientific Achievement Award of the American Medical Association in 1970. He was elected to membership in the American Association for the Advancement of Science (1949), the American Academy of Arts and Sciences (1963), and the American Institute of Chemists (1968).



Choh Hao Li

THE
ILLUSTRATED SCIENCE
DICTIONARY

Tremor to Zymolysis

KEY TO PRONUNCIATION

The diacritical marks are:

ə	b*a*n*a*n*a*, *a*but	e	b*e*t	th	*th*in
ᵊ	preceding l, m, n as in batt*le*	ē	b*ea*t	t͟h	*th*en
ə̇	*e*lectric	i	t*i*p	ü	r*u*le, f*oo*l
ər	f*ur*ther	ī	b*i*te	u̇	p*u*ll, w*oo*d
a	m*a*t	j	*j*ob, gem	ue	German h*ü*bsch
ā	d*ay*	ŋ	s*ing*	u̅e	French r*ue*
ä	cot, f*a*ther	ō	b*o*ne	yü	*u*nion
au̇	n*ow*, *ou*t	ȯ	*saw*, *a*ll	zh	vi*si*on
		ȯi	c*oi*n		

ˈ mark preceding the syllable with strongest stress.

ˌ mark preceding a syllable with secondary stress.

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tremor \ˈtrem-ər\ *n.*

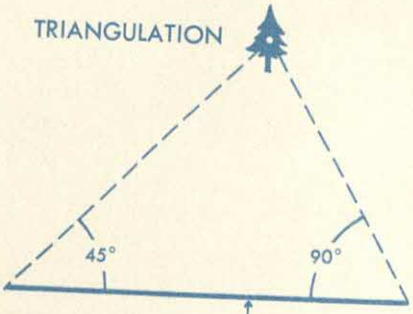
EARTH SCIENCE. A quivering or shaking movement of land surfaces; a small, or low-intensity, earthquake.

A seismograph may detect a TREMOR *at a considerable distance from its source.*

triangle \ˈtrī-ˌaŋ-gəl\ *n.*

MATHEMATICS. A closed geometric figure with three sides and three angles; a three-sided polygon.

The sum of the angles of any TRIANGLE *is equal to 180 degrees.*



Surveyor measures base line and two angles to determine position of tree

triangulation \(ˌ)trī-ˌaŋ-gyə-ˈlā-shən\ *n.*

ENGINEERING and MATHEMATICS. A method of surveying, based on the use of successive triangles, beginning with an accurately-measured base line. Points are sighted and angles measured from the ends of the base line, and the unmeasured sides of the triangle are then computed by trigonometry and, in turn, used as base lines of new triangles. In this way, a large region of the earth's surface may be surveyed.

The process of TRIANGULATION *is widely used in geodetic surveys and in the preparation of maps.*

triboluminescence \ˌtrī-bō-ˌlü-mə-ˈnes-ᵊn(t)s\ *n.*

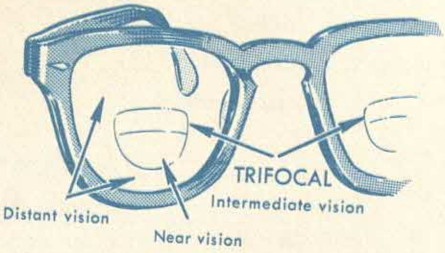
PHYSICS. The emission of faint light by certain substances, especially crystals, when they undergo friction by being ground or crushed. Triboluminescence is thought to be caused by piezoelectric discharges.

A slight amount of TRIBOLUMINESCENCE *occurs when sugar crystals are crushed.*

trifocal \(ˈ)trī-ˈfō-kəl\ *adj.*

MEDICINE. Referring to corrective lenses made up of three segments with different focal lengths.

TRIFOCAL *lenses correct near, intermediate and distant vision.*



trigonometry \ˌtrig-ə-ˈnäm-ə-trē\ *n.*

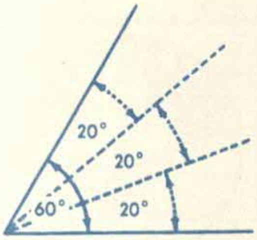
MATHEMATICS. That branch of mathematics that originally was concerned with the study of relations between the sides and angles of triangles and with the application of these relations to the solution of practical problems. At present, more emphasis is placed on theoretical and analytical considerations, such as relationships among the functions, graphs, variations, inverse functions and solutions of trigonometric equations.

A basic knowledge of TRIGONOMETRY *is required in practically all phases of engineering.*

trinomial \trī-'nō-mē-əl\ *n.*

MATHEMATICS. An expression, or polynominal, that has three terms.

The expression $2x^2 - x + 10$ is a TRINOMIAL.



TRISECT

triode \'trī-ˌōd\ *n.*

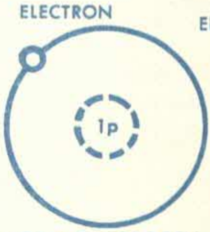
ENGINEERING. A vacuum tube incorporating three separate elements.

A TRIODE *usually contains an anode, a cathode and a grid that controls the flow of electrons from one to the other.*

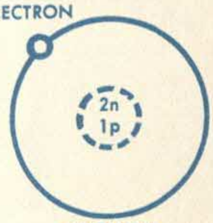
triple point \'trip-ᵊl 'pȯint\

CHEMISTRY and PHYSICS. The temperature and pressure at which a given substance can exist as a solid, liquid and gas at the same time.

The TRIPLE POINT *for water is 0.0099° C. at 0.006 atmosphere of pressure.*



NORMAL HYDROGEN
$_1H^1$
(ATOM)



TRITIUM
$_1H^3$
(ATOM)

trisect \'trī-ˌsekt\ *v.*

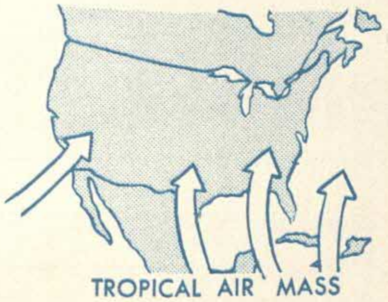
MATHEMATICS. To separate, or divide, into three equal parts.

It is ordinarily impossible to TRISECT *an angle by using only a straightedge and compasses.*

tritium \'trit-ē-əm\ *n.*

CHEMISTRY and PHYSICS. A heavy form (isotope) of the element hydrogen that has a nucleus containing one proton and two neutrons, as compared with ordinary hydrogen that has one proton and no neutrons in its nucleus. Tritium is radioactive and occurs in nature in very small quantities (about 5 atoms in every billion billion hydrogen atoms). It is used as a tracer; see *tracer, isotope* and *deuterium.*

Rainwater contains more TRITIUM *than does ocean water, possibly because tritium is formed by reactions with cosmic rays in the upper atmosphere.*



TROPICAL AIR MASS

tropical air mass \'träp-i-kəl 'a(ə)r 'mas\

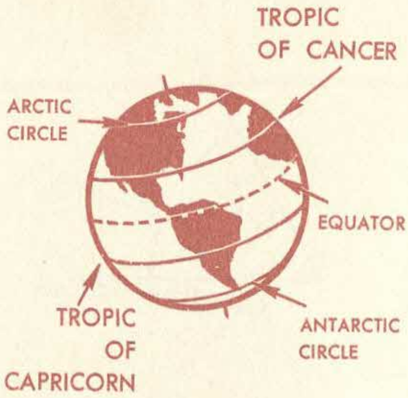
EARTH SCIENCE. A large body of air that originates or acquires its characteristics in the tropics.

A TROPICAL AIR MASS *that forms over the ocean is warm and moist, while one that forms over land is hot and dry.*

tropical year \'träp-i-kəl 'yi(ə)r\

ASTRONOMY. The time required for one revolution of the earth around the sun with respect to the vernal equinox. The length of the tropical year is 365 days, 5 hours, 48 minutes and 46 seconds; see *vernal equinox* and *sidereal year.*

The calendar year beginning on January 1 is slightly shorter than the TROPICAL YEAR *and is adjusted by having an extra day in each leap year.*



Tropic of Cancer \'träp-ik əv 'kan(t)-sər\

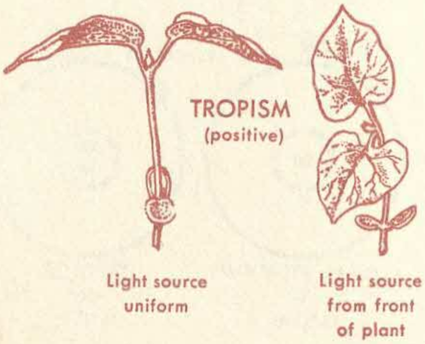
EARTH SCIENCE. An imaginary line parallel to the earth's equator at a latitude of 23½ degrees north. It is an imaginary line on the earth from which the sun would appear to pass directly overhead at the summer solstice (June 22).

At some time during the course of a year, the sun appears to pass directly overhead to all observers in the belt bounded by the TROPIC OF CANCER *and the Tropic of Capricorn.*

Tropic of Capricorn \'träp-ik əv 'kap-ri-ˌkȯ(ə)rn\

EARTH SCIENCE. An imaginary line parallel to the earth's equator at a latitude of 23½ degrees south. It is an imaginary line on the earth from which the sun would appear to pass directly overhead at the winter solstice (December 22).

The belt between the TROPIC OF CAPRICORN *and the Tropic of Cancer is known as the Torrid Zone.*



tropics \'träp-iks\ *n.*

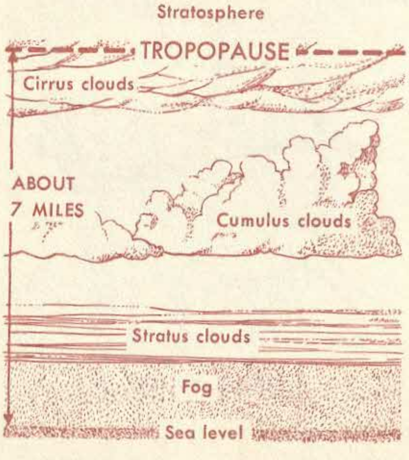
EARTH SCIENCE. That area of the earth's surface between the Tropics of Cancer and Capricorn. The tropics include all points on the earth's surface over which the sun is vertical at some time during the year; also known as the Torrid Zone.

Certain areas of the TROPICS *have over 100 inches of rainfall per year.*

tropism \'trō-ˌpiz-əm\ *n.*

BIOLOGY. The movement of an organism or part of an organism toward or away from external stimuli, such as light, water, gravity or heat.

Movement toward a stimulus is called positive TROPISM *and movement away is called negative tropism.*



tropopause \'trō-pə-ˌpȯz\ *n.*

EARTH SCIENCE. The layer of the atmosphere between the top of the troposphere and the bottom of the stratosphere. It occurs at an average altitude of 7 miles but varies with latitude and season.

Most of the weight of the earth's atmosphere lies below the TROPOPAUSE.

troposphere \'trō-pə-ˌsfi(ə)r\ *n.*

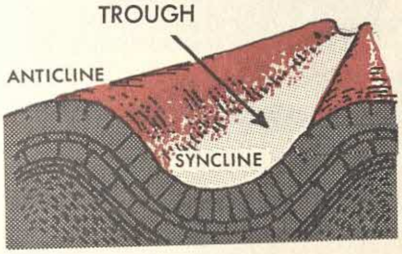
EARTH SCIENCE. The lower layer of the earth's atmosphere, characterized by air turbulence due to convection currents and varying in thickness from 30,000 to 60,000 feet.

The temperature of air in the TROPOSPHERE *generally decreases with altitude, usually at a rate of about 3.5° F. per thousand feet.*

trough \'trȯf\ *n.*

EARTH SCIENCE. A depression, or basin, between ridges, or the bottom of a syncline; also, the depression between wave crests on water; also, an elongated area of low pressure in the atmosphere.

A TROUGH *may be formed if a long, narrow block of the earth's crust sinks relative to the land on either side.*



troy weight \'trȯi 'wāt\

MATHEMATICS. A system of weights, used to weigh fine metals and precious stones. Its basic unit is equal to 12 ounces, or 5,760 grains.

TROY WEIGHT *derives its name from Troyes, France, where it was first used.*

trypsin \'trip-sən\ *n.*

PHYSIOLOGY. One of several enzymes that aid in the digestion of proteins. It is produced in the small intestine by the action of another enzyme upon the compound trypsinogen, present in the pancreatic gland.

TRYPSIN *can act on raw proteins, but it is more effective on cooked proteins or on those that have been partly digested in the stomach.*

tsunami \(t)sü-'näm-ē\ *n.*

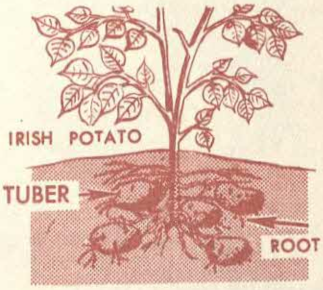
EARTH SCIENCE. A giant wave caused by an earthquake or volcanic eruption on the ocean floor. Its wave front is only a few feet high when at sea but rises as high as 100 feet as it moves across shallow water to the shore. It is sometimes incorrectly called a tidal wave.

A TSUNAMI *may travel across the ocean at speeds of 300 to 500 miles per hour.*

tuber \'t(y)ü-bər\ *n.*

BOTANY. A short, fleshy, underground stem that functions in food storage and asexual reproduction.

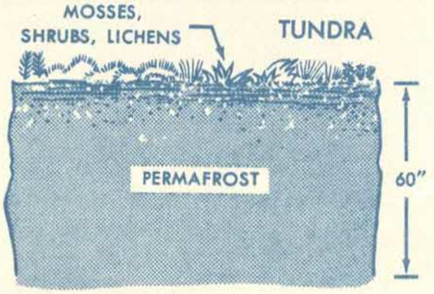
The skin covering the Irish potato TUBER *is bark that has little nutritive value.*



tubercle \'t(y)ü-bər-kəl\ *n.*

1. MEDICINE and ZOOLOGY. Any small, abnormal, hard growth on or in a structure of the body; also, a normal knoblike structure, as on a bone. 2. BOTANY. A small tuber or tubelike growth on the roots of plants or a wartlike growth on a plant.

Tuberculosis is named for the characteristic TUBERCLE *that forms around the bacteria causing the disease.*



tularemia \ˌtü-lə-'rē-mē-ə\ *n.*

MEDICINE and ZOOLOGY. An infectious bacterial disease of rodents and some other mammals that is transmissible to man. The disease can be transmitted through a bite or through handling an infected animal and causes a long-term fever.

Rabbits are sometimes infected with TULAREMIA.

tumor \'t(y)ü-mər\ *n.*

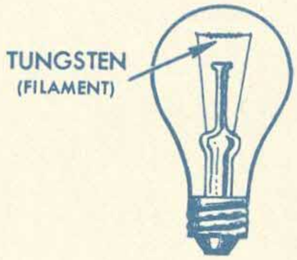
MEDICINE. An abnormal growth that is not part of the normal body structure and that has no physiological function.

A TUMOR *may often be removed from the body by surgery.*

tundra \'tən-drə\ *n.*

EARTH SCIENCE. A swampy plain found at high altitudes and in the arctic and subarctic regions of North America, Europe and Asia. A tundra is characterized by large areas of a black muck or swampland soil covering permanently-frozen subsoil.

The trees that grow on TUNDRA *are usually dwarf varieties.*



tungsten \'təŋ(k)-stən\ *n.*

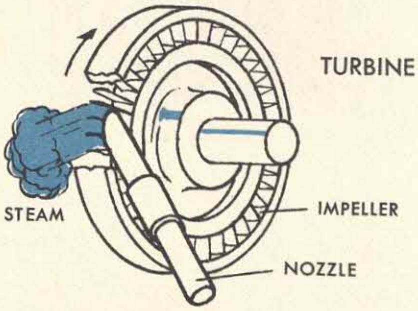
CHEMISTRY. A heavy metallic element that has a high melting point (3,370° C.) and that does not react readily with other substances at ordinary temperatures; also called wolfram. Symbol, W; atomic number, 74; atomic weight, 183.85.

The filament of an ordinary light bulb is mostly TUNGSTEN.

turbidity current \ˌtər-'bid-ət-ē 'kər-ənt\

EARTH SCIENCE. A current produced by the higher density of muddy, or turbid, water relative to the surrounding water; see *density current.*

Mud particles that result in a TURBIDITY CURRENT *may be caused by the erosive action of waves.*



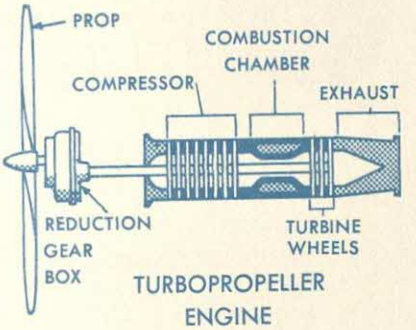
turbine \'tər-bən\ *n.*

ENGINEERING. A machine in which a stream of water, steam or gas turns a fanlike wheel. A turbine is used in changing stored energy into mechanical energy.

A drive shaft can be attached to the rotor, or fan, of a TURBINE *and can be used to drive an electric generator.*

turboelectric generator \ˌtər-(ˌ)bō-i-'lek-trik 'jen-ə-ˌrā-tər\
ENGINEERING. A device that produces current electricity. It is driven by a turbine, the source of power being a stream of water, steam or gas; see *turbine*.

Where water is not available for producing electricity, a steam-driven TURBOELECTRIC GENERATOR *may be used.*



TURBOPROPELLER ENGINE

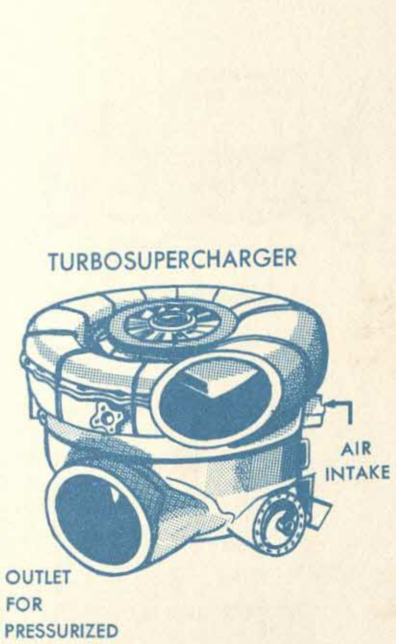
turbojet engine \'tər-bō-ˌjet 'en-jən\
AERONAUTICS and ENGINEERING. A type of jet engine in which the hot gases, before they leave the engine, drive a turbine that is connected to an air compressor. The compressor provides compressed air in which fuel is burned, thereby producing more hot gases.

The turbine blades in a TURBOJET ENGINE *must be constructed of special materials that will withstand very high temperatures.*

turbopropeller engine \ˌtər-(ˌ)bō-prə-'pel-ər 'en-jən\
AERONAUTICS and ENGINEERING. An internal-combustion engine similar to a turbojet engine, except that the compressor shaft extends forward through reduction gearing to a propeller; also called turboprop engine.

A TURBOPROPELLER ENGINE *produces thrust principally by a propeller, although some thrust is produced by gases escaping from the rear of the engine.*

TURBOSUPERCHARGER


AIR INTAKE
OUTLET FOR PRESSURIZED AIR AND FUEL MIXTURE

turbosupercharger \ˌtər-(ˌ)bō-'sü-pər-ˌchär-jər\ *n.*
ENGINEERING. On piston engines, a device used to supply the engine with enough air to operate efficiently at high altitudes. A turbosupercharger has an exhaust-driven turbine that rotates the impeller of an air compressor, forcing denser air into the fuel-air mixture.

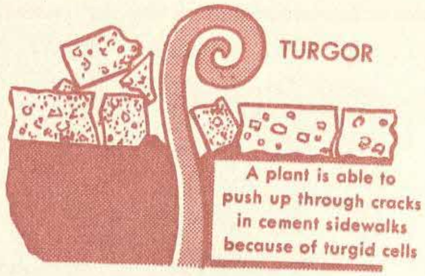
Through the use of a TURBOSUPERCHARGER, *commercial and military aircraft can take advantage of the high-altitude winds known as the jet stream.*

turbulence \'tər-byə-lən(t)s\ *n.*
EARTH SCIENCE. A condition of irregular air movements in the atmosphere, caused by unequal convection currents, by air flowing over an uneven surface or by winds with different directions or speeds flowing past one another; also, the mixing of water currents so that the separate currents can no longer be recognized (turbulent flow).

TURBULENCE *in the atmosphere may sometimes be observed by watching a rising column of smoke.*

turgor \'tər-gər\ *n.*
BIOLOGY. Fluid pressure within living cells.

When a plant is deprived of water, TURGOR *is reduced and the plant wilts.*

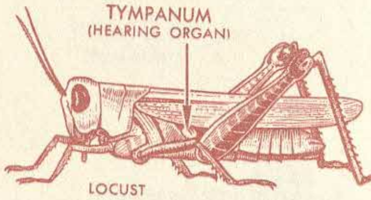

TURGOR
A plant is able to push up through cracks in cement sidewalks because of turgid cells

twenty-twenty vision \'twent-ē 'twent-ē 'vizh-ən\
MEDICINE and PHYSIOLOGY. Normal vision, or visual acuity based on an ability to read at twenty feet letters ⅓ inch in diameter.

Most nearsighted people can have TWENTY-TWENTY VISION *by wearing corrective lenses.*

twins \'twinz\ *n.*
Two individuals born at a single birth. They may result from one complete division of a fertilized egg (identical twins) or from two fertilized eggs (fraternal twins); see *identical twins* and *fraternal twins.*

In the United States, human TWINS *occur only once in about every 90 births.*



tympanum \'tim-pə-nəm\ *n.*
ANATOMY and ZOOLOGY. The thin, vibrating tissue of a hearing organ; an eardrum.

The TYMPANUM *of the common locust is located on the surface of the first abdominal segment.*

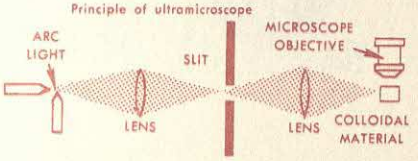
Tyndall effect \'tin-dəl i-'fekt\
PHYSICS. The scattering of a beam of light as it passes through a transparent medium with the result that the path becomes visible. It is caused by light being reflected from particles that are too small to be visible (colloidal particles) and yet larger than molecules.

The TYNDALL EFFECT *can be observed in the beam from a searchlight as it is directed up into the sky at night.*

typhoon \tī-'fün\ *n.*
EARTH SCIENCE. An Asiatic tropical cyclone; also, in the Far East region of the Pacific Ocean, a hurricane. A typhoon receives most of its energy from the condensation of water vapor; see *cyclone* and *hurricane.*

A TYPHOON *is more common during the late summer and early fall months than at other times of the year.*

U



ULTRAMICROSCOPE

ultracentrifuge \ˌəl-trə-'sen-trə-ˌfyüj\ *n.*
BIOLOGY and CHEMISTRY. A very high-speed centrifuge used to separate colloidal particles suspended in a liquid by producing forces many times that of gravity; see *centrifuge* and *colloid.*

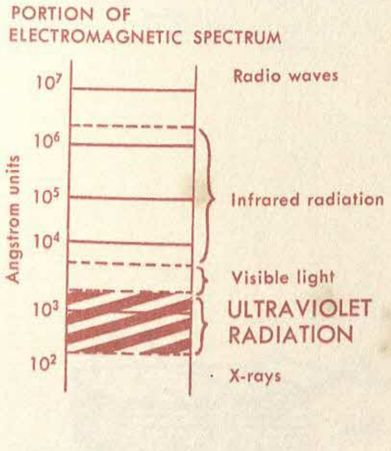
An ULTRACENTRIFUGE *may produce a force on suspended particles that is about 400,000 times the force of gravity.*

ultrahigh frequency \'əl-trə-ˌhī 'frē-kwən-sē\
PHYSICS. Referring to any radio wave in the range of 300 to 3,000 megacycles per second; *abbr.* uhf.

Commercial television channels may operate on either very high frequency or ULTRAHIGH FREQUENCY.

ultramicroscope \ˌəl-trə-'mī-kro-ˌskōp\ *n.*
A microscope that uses a special lighting system to make very small (colloidal) particles visible. The particles, suspended in an air- or liquid-filled chamber, are lighted by an intense beam of light from the side so that each particle appears as a bright point of light.

An ULTRAMICROSCOPE *does not magnify more than an ordinary microscope.*



ultrasonic \ˌəl-trə-'sän-ik\ *adj.*
PHYSICS. Referring to high-pitched sound vibrations beyond the range of human hearing. They are usually those vibration frequencies above 18,000 cycles per second, sometimes incorrectly called supersonic.

Some sounds that are ULTRASONIC *for human beings can be detected by such animals as the dog and the bat.*

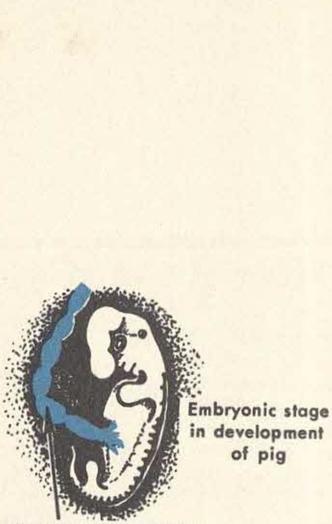
ultraviolet radiation \ˌəl-trə-'vī-ə-lət ˌrād-ē-'ā-shən\
PHYSICS. Energetic, invisible rays beyond the violet end of the visible spectrum. Ultraviolet radiation occurs in sunlight and is produced by certain artificial sources, such as a mercury arc. It has a shorter wavelength and a higher frequency than visible light and is thought to be a major cause of sunburn.

Ordinary window glass filters out most of the ULTRAVIOLET RADIATION *in sunlight.*

umbilical cord \\ˌəm-'bil-i-kəl 'kȯ(ə)rd\\

1. ANATOMY and ZOOLOGY. In mammals, a tube containing blood vessels and connecting the unborn young to the placenta. 2. ASTRONAUTICS. An electrical cable connecting a rocket to its launching equipment. It is disconnected just before lift-off.

Blood in the vessels of the UMBILICAL CORD *carries nourishment and oxygen to the embryo and waste products away from it.*



Embryonic stage in development of pig

UMBILICAL CORD

umbilicus \\ˌəm-'bil-i-kəs\\ *n.*

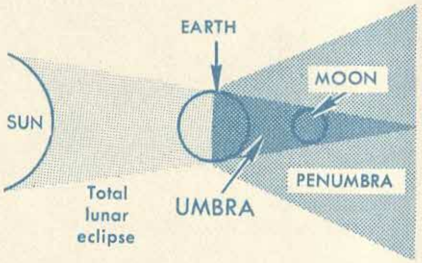
ANATOMY and ZOOLOGY. A scar on the abdomen of mammals that marks the place where the umbilical cord was attached to the unborn young; also called the navel.

The UMBILICUS *is formed by the rapid growth of scar tissue, which normally turns inward and forms a small depression.*

umbra \\'əm-brə\\ *n.*

1. ASTRONOMY. The dark, central portion of a planet's or satellite's shadow from which all sunlight is excluded; also, the central, darker region of a sunspot. 2. PHYSICS. The dark inner part of a shadow that receives no direct light.

During a total eclipse of the moon, the moon passes through the UMBRA *of the earth's shadow.*



uncertainty principle \\ˌən-'sərt-ᵊn-tē 'prin(t)-s(ə-)pəl\\

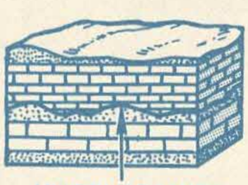
PHYSICS. A belief that both the position and the speed of a subatomic particle, such as an electron or a proton, cannot be determined at the same time. The belief is based on the fact that the process of measuring one characteristic greatly changes the other.

The UNCERTAINTY PRINCIPLE *does not seem to limit the measurement of both speed and position of objects large enough to be seen.*

unconformity \\ˌən-kən-'fȯr-mət-ē\\ *n.*

EARTH SCIENCE. The surface between two rock layers or masses that represents a period of time during which either erosion took place or no sediments were deposited; see *disconformity* and *nonconformity.*

The period of time represented by an UNCONFORMITY *may be determined if fossils are found in the rock layers above and below it.*



UNCONFORMITY

undertow \\'ən-dər-ˌtō\\ *n.*

EARTH SCIENCE. A seaward current beneath incoming waves, caused by the return of water from waves breaking on the shore; see *rip current.*

Fine rock particles are carried from the shore to deeper water by UNDERTOW.

UNGULATE

ungulate \ˈəŋ-gyə-lət\ *adj.*

ZOOLOGY. Having hoofs or shaped like a hoof.

Taxonomists formerly grouped UNGULATE *mammals into the large order Ungulata.*

unicellular \ˌyü-ni-ˈsel-yə-lər\ *adj.*

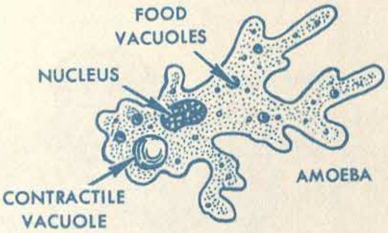
BIOLOGY. Referring to an organism that consists of only one cell.

Many of the plants making up the surface scum on ponds are UNICELLULAR.

unidirectional \ˌyü-ni-də-ˈrek-shnəl\ *adj.*

PHYSICS. Referring to any motion that proceeds in only one direction. Unidirectional frequently refers to a direct electric current or to radio waves transmitted in a narrow beam.

The flow of electric current from a dry cell is UNIDIRECTIONAL.



UNICELLULAR

uniformitarianism \ˌyü-nə-ˌfȯr-mə-ˈter-ē-ə-ˌniz-əm\ *n.*

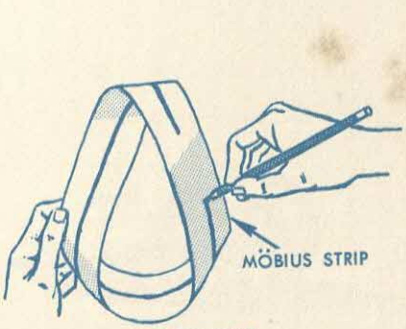
EARTH SCIENCE. A concept or combination of ideas suggesting that the processes now producing changes in the earth's surface also occurred in much the same way, although at varying rates, in the past. The concept is sometimes summed up by the statement, "The present is the key to the past."

James Hutton of Scotland first presented the concept of UNIFORMITARIANISM *in 1785.*

uniform motion \ˈyü-nə-ˌfȯrm ˈmō-shən\

PHYSICS. The movement of an object in a straight line and at a constant speed. Such movement occurs only when all the forces acting on a moving object cancel each other or when there are no forces acting.

Although a rifle bullet may seem to be in a state of UNIFORM MOTION, *air resistance causes it to slow down.*



UNILATERAL

unilateral \ˌyü-ni-ˈlat-ə-rəl\ *adj.*

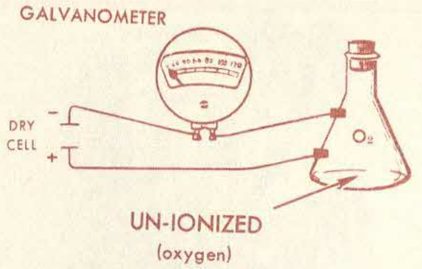
1. MATHEMATICS. One-sided; also, referring to a sheetlike configuration that has only one surface. 2. BIOLOGY. Produced, or arranged, on only one side. 3. MEDICINE. Affecting only one side of the body.

A line can be drawn from any point of a UNILATERAL *sheet, as a Möbius strip, to any other point on the surface without crossing over its edges or without piercing the sheet.*

un-ionized \ən-'ī-ə-nīzd\ *adj.*

CHEMISTRY and PHYSICS. Referring to a substance normally composed of electrically-neutral molecules, as oxygen and sugar. An un-ionized substance is distinguished from substances composed of positive and negative ions, such as salt and most crystalline substances; see *ion* and *ionization.*

Any liquid or gas that does not conduct electricity is UN-IONIZED.



uniparous \yü-'nip-ə-rəs\ *adj.*

BIOLOGY. Referring to the production of one egg or one offspring at a time.

The UNIPAROUS *walrus whelps a pup every second year.*

unit cell \'yü-nət 'sel\

EARTH SCIENCE. The smallest amount of a crystal lattice which has all the features of the mineral from which it is taken.

A UNIT CELL *of halite has four sodium and four chlorine ions.*

unity \'yü-nət-ē\ *n.*

MATHEMATICS. Equal to one, or the same as one.

The value of a quantity is not changed if it is multiplied by UNITY.

univalent \ˌyü-ni-'vā-lənt\

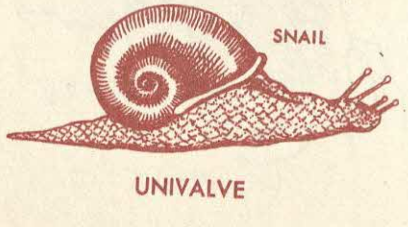
1. CHEMISTRY. (Adj.). Referring to an atom that gains or loses only one electron or that forms only one covalent bond in forming compounds; also, referring to an ion with an electrical charge of +1 or −1; see *covalent bond* and *ion.* 2. BIOLOGY (N.). An unpaired chromosome during the first division of meiosis.

It is possible for four UNIVALENT *atoms of hydrogen to react with one atom of carbon that has a valence of four.*

univalve \'yü-ni-ˌvalv\ *adj.*

ZOOLOGY. Referring to an animal with a one-piece shell.

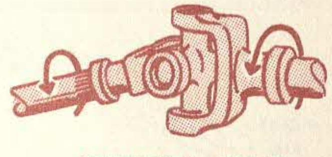
Relatives of the UNIVALVE *snail include the bivalve clam and the shell-less garden slug.*



universal gravitation \ˌyü-nə-'vər-səl ˌgrav-ə-'tā-shən\

PHYSICS. A concept of gravity developed by Sir Isaac Newton. His statement says that every particle in the universe attracts every other particle with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

The concept of UNIVERSAL GRAVITATION *has been useful to astronomers and other scientists in understanding the motions of planets in the solar system.*



UNIVERSAL JOINT
(AUTOMOTIVE)

universal joint \ˌyü-nə-ˈvər-səl ˈjȯint\

ENGINEERING. A device that connects two rotating shafts that are nearly in a straight line. In an automobile, two universal joints are used in connecting the drive shaft from the engine to the differential on the rear axle.

A UNIVERSAL JOINT *is inefficient if the two shafts it connects make an angle of less than 165 degrees with each other.*

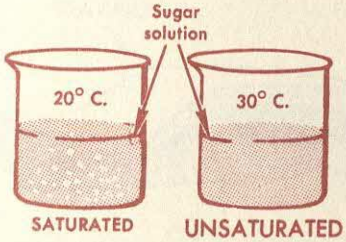
universal time \ˌyü-nə-ˈvər-səl ˈtīm\

Another term for Greenwich time. See *Greenwich time.*

universe \ˈyü-nə-ˌvərs\ *n.*

ASTRONOMY and EARTH SCIENCE. The entire celestial cosmos, observed or postulated, in which all matter exists and all events occur; also, one celestial system, as the Milky Way.

Some astronomers support the theory of an expanding UNIVERSE, *while others feel that the available evidence best supports the steady-state theory.*



UNSATURATED

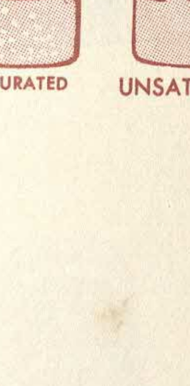
unsaturated \ˌən-ˈsach-ə-ˌrāt-əd\ *adj.*

1. CHEMISTRY. Referring to a substance that can absorb or dissolve more of a second substance than it has already dissolved at a given temperature; also, frequently referring to a molecule of a compound that contains at least one double or triple covalent bond; see *covalent bond.* 2. EARTH SCIENCE. Referring to air containing less water vapor than it can normally contain at a given temperature.

A sugar solution that is saturated at 20° C. will be UNSATURATED *if its temperature is raised to 30° C.*

unsoluble \ˌən-ˈsäl-yə-bəl\ *adj.*

CHEMISTRY. Insoluble. See *insoluble.*



$$\begin{array}{c} H \\ | \\ H-C-O-NO_2 \\ | \\ H-C-O-NO_2 \\ | \\ H-C-O-NO_2 \\ | \\ H \end{array}$$

UNSTABLE
(nitroglycerin)

unstable \ˌən-ˈstā-bəl\ *adj.*

1. CHEMISTRY. Referring to a chemical compound that readily decomposes, or breaks down, into two or more substances; also, referring to a compound or element that changes its molecular or crystal structure to a more permanent form, as ozone (O_3) changing to oxygen (O_2). 2. PHYSICS. Referring to a position that is not permanent and that is apt to change.

Nitroglycerin is very UNSTABLE *and may decompose suddenly in a violent explosion if jarred or vibrated.*

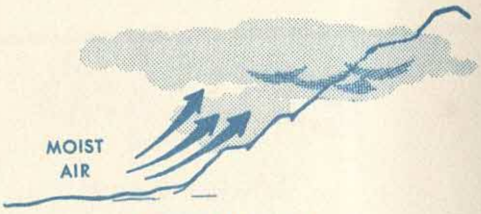
unstratified \ˌən-'strat-ə-ˌfīd\ *adj.*
EARTH SCIENCE. Referring to rock structures or deposits of loose material that do not form in layers or strata.

Granite, basalt and marble usually occur as UNSTRATIFIED *rocks.*

unstriated muscles \ˌən-'strī-ˌāt-əd 'məs-əlz\
ANATOMY. Smooth muscles. See *smooth muscles.*

uphill orbit \'əp-ˌhil ȯr-bət\
ASTRONAUTICS. That part of a satellite's orbit that carries the satellite farther away from the body around which it is orbiting; see *downhill orbit.*

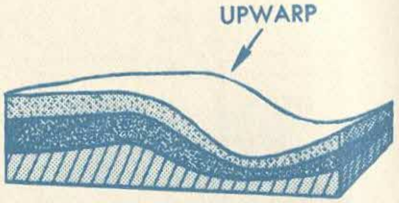
A satellite tends to lose speed during UPHILL ORBIT.



UPSLOPE FOG

upslope fog \'əp-ˌslōp 'fȯg\
EARTH SCIENCE. A fog formed when moist air cools as it moves up a mountain slope or hillside.

A cloud formation in contact with a mountainside may be an UPSLOPE FOG.

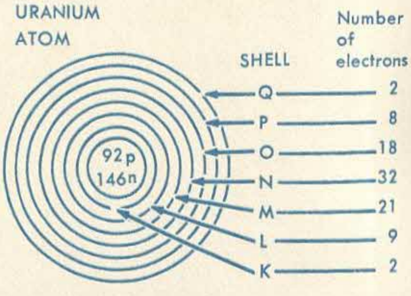


upwarp \'əp-ˌwȯ(ə)rp\ *n.*
EARTH SCIENCE. An extensive area of the earth's crust that has been uplifted; a broad anticline.

An UPWARP *is the result of opposing forces in the earth's crust.*

uranium \yu̇-'rā-nē-əm\ *n.*
CHEMISTRY. A metallic element that is radioactive and active chemically. It is found in nature combined with oxygen in minerals such as carnotite and pitchblende. Uranium has three natural isotopes with atomic masses of 234, 235 and 238; see *isotope.* Symbol, U; atomic number, 92; atomic weight, 238.03.

All atoms of URANIUM *can be split, or fissioned, when their nuclei are hit by neutrons traveling at the right speed.*



URANIUM

urea \yu̇-'rē-ə\ *n.*
1. PHYSIOLOGY and ZOOLOGY. $NH_2 \cdot CO \cdot NH_2$. The chief nitrogen-containing compound in urine. Urea is the final waste product from decomposition of protein compounds in the body and is believed to form in the liver from amino acids and the compounds of ammonia; also called carbamide. 2. CHEMISTRY. NH_2CONH_2. A white, crystalline substance used in producing plastics and in other chemical processes.

UREA *was the first organic compound to be synthesized in the laboratory.*

ureter \yu̇-'rēt-ər\ *n.*
ANATOMY and ZOOLOGY. In mammals, a duct or tube that carries urine from the kidney to the urinary bladder. In some other

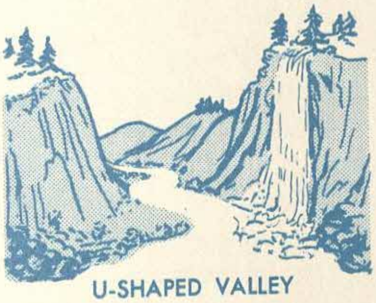
vertebrates, the ureter is the tube from the kidney to the cloaca.

The middle muscular layer of the URETER *alternately contracts and relaxes in forcing urine into the urinary bladder.*

urethra \yu̇-'rē-thrə\ *n.*

ANATOMY and ZOOLOGY. In mammals, the canal leading from the urinary bladder to the outside of the body.

The male URETHRA *also serves as the spermatic duct.*



U-SHAPED VALLEY

urinary bladder \'yu̇r-ə-ˌner-ē 'blad-ər\

ANATOMY and ZOOLOGY. A membranous sac located in the front part of the pelvic cavity in mammals and serving as a temporary storage place for urine.

The wall of the URINARY BLADDER *is elastic.*

urine \'yu̇r-ən\ *n.*

PHYSIOLOGY and ZOOLOGY. Waste material secreted by kidneys. It is largely an aqueous solution of urea.

URINE *is made up of about 96 percent water and 4 percent dissolved wastes.*

U-shaped valley \'yü-ˌshāpd 'val-ē\

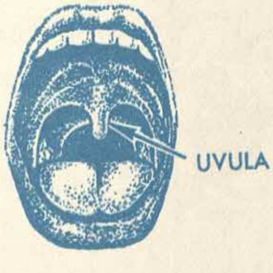
EARTH SCIENCE. A type of valley formed by the movement of a mountain glacier. It has steep walls and a rather flat bottom.

Waterfalls are common in a U-SHAPED VALLEY, *where streams flow over the valley walls and join a larger stream in the valley.*

USP

CHEMISTRY and MEDICINE. An abbreviation for *United States Pharmacopeia*, a publication containing standards for drug manufacture established under expert medical supervision.

In chemistry, USP *refers to a chemical with impurities not exceeding those specified in the publication.*



uterus \'yüt-ə-rəs\ *n.*

ANATOMY and ZOOLOGY. In the female mammal, the thick-walled, hollow, muscular organ in which the young develop before birth. The uterus contracts during birth and pushes the young through the birth passage.

The walls of the UTERUS *contain many blood vessels from which unborn young receive nourishment through the placenta.*

uvula \'yü-vyə-lə\ *n.*

ANATOMY. A soft, fleshy lobe located above the back, or root, of the tongue and projecting down from the soft palate.

The French "r" sound is produced by breath passing between the UVULA *and the back of the tongue.*

V

vaccination \ˌvak-sə-ˈnā-shən\ *n.*

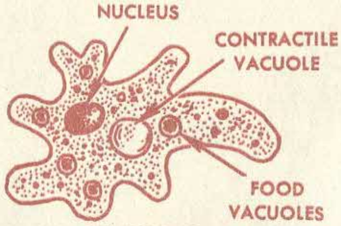
MEDICINE. The injection or intake of a vaccine into the body to produce immunity to a disease.

VACCINATION *has nearly eliminated smallpox in some countries.*

vaccine \vak-ˈsēn\ *n.*

MEDICINE. A suspension of killed or weakened microorganisms, of the toxins they produce, or of both, used for the prevention or treatment of an infectious disease.

The first VACCINE *against smallpox, discovered by Dr. Edward Jenner in 1796 in England, is still used effectively.*



VACUOLE
(of amoeba)

vacuole \ˈvak-yə-ˌwōl\ *n.*

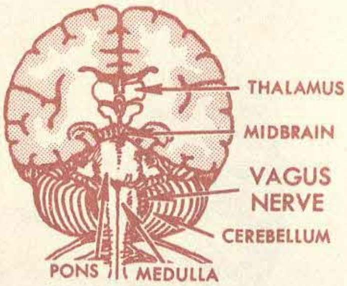
BIOLOGY. A usually-spherical cavity within the cytoplasm of plant and animal cells. It is surrounded by a membrane and filled with liquid or solid matter, or both. A vacuole functions in digestion, excretion and food storage.

Food engulfed by an amoeba is digested within a food VACUOLE.

vacuum tube \ˈvak-yə(-wə)m ˈt(y)üb\

PHYSICS. A glass or metal container from which most of the air has been removed and that is usually used to provide a space through which electrons may move freely between metal plates, called electrodes, that are mounted inside; see *electron tube.*

Such devices as a fluorescent lamp, neon sign or radio tube utilize a VACUUM TUBE.



vagus nerve \ˈvā-gəs ˈnərv\

ANATOMY. Either of the tenth pair of cranial nerves. They stem from the medulla of the brain and branch downward to such organs as the heart, bronchi, stomach, pancreas and small intestine. A vagus nerve contains both sensory and motor fibers.

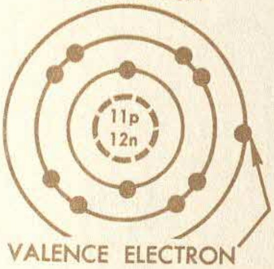
In the abdomen, the VAGUS NERVE *stimulates gastric and pancreatic secretion.*

valence \ˈvā-lən(t)s\ *n.*

CHEMISTRY. A measure of the capacity of an atom of a given element to combine with atoms of other elements; also, the number of electrons an atom gains or loses in reacting with other atoms or the number of electron pairs the atom shares with other atoms in a molecule.

The fact that copper and sulfur form two different compounds, CuS *and* Cu_2S*, is evidence that an element may have more than one* VALENCE.

SODIUM ATOM



valence electron \'vā-lən(t)s i-'lek-ˌträn\

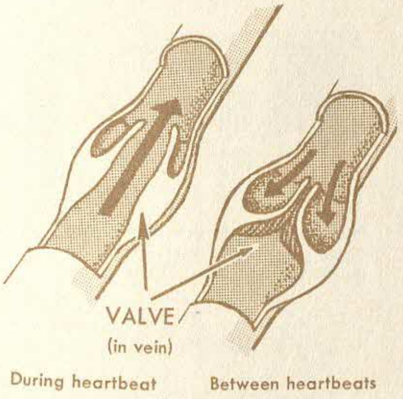
CHEMISTRY. Any electron in the outermost shell, or energy level, of an atom. Such an electron may be lost or shared in forming compounds.

Sodium has only one VALENCE ELECTRON.

valence number \'vā-lən(t)s 'nəm-bər\

CHEMISTRY. The combining capacity of an atom, determined by the number of electrons lost or added, or by the number of pairs of shared electrons.

The VALENCE NUMBER *for hydrogen is 1.*



valence shell \'vā-lən(t)s 'shel\

CHEMISTRY. Those electrons in the outermost shell of an atom. A valence shell contains those electrons that are lost or shared in forming compounds and may contain from one to eight electrons, depending on the chemical element.

The chemical properties of an element can be explained largely by the number of electrons in the VALENCE SHELL *of its atom.*

valley \'val-ē\ *n.*

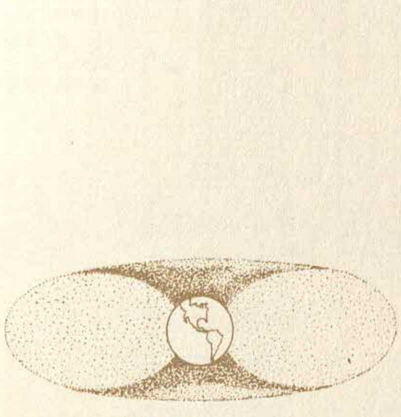
EARTH SCIENCE. A depression in the earth's surface that may be shallow or deep, narrow or wide, and usually contains a stream.

A VALLEY *is most often the result of the erosion or cutting action of the stream that flows in it.*

valve \'valv\ *n.*

1. ANATOMY. A structure, such as a membranous fold of tissue within an organ or vessel, that prevents backflow of fluid within the organ or passage. 2. ENGINEERING. An adjustable mechanical device that controls the passage of material, usually liquid or gas, through a tube or an opening; also, sometimes, an electron tube.

The bicuspid VALVE *on the left side of the heart allows blood to enter the ventricle but prevents backflow when the ventricle contracts and forces blood into the aorta.*



VAN ALLEN BELT

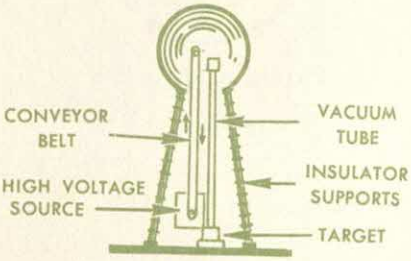
Van Allen belt \va-'nal-ən 'belt\

ASTRONOMY. A doughnut-shaped radiation belt, consisting of high-energy protons and electrons, that encircles the earth and that extends from approximately 400 to 40,000 miles above the earth's surface. The Van Allen belt is least intense above the earth's magnetic poles.

Radiation in the VAN ALLEN BELT *could be a serious danger to the passengers in an unshielded spacecraft.*

Van de Graaff generator \'van də 'graf 'jen-ə-ˌrāt-ər\
PHYSICS. A device used to produce and direct a high-speed stream of electrically-charged particles, as electrons or protons, at a target for experimental purposes. It usually consists structurally of a large metal sphere on top of a tube made of insulating material; see *particle accelerator.*

A one-million-volt VAN DE GRAAFF GENERATOR *can produce X rays that will penetrate a five-inch-thick steel plate.*



VAN DE GRAAFF GENERATOR

van der Waals' forces \'van dər 'wälz 'fō(ə)rs-əs\
CHEMISTRY and PHYSICS. Forces of attraction among molecules that are considered different from chemical bonds or gravitational forces. These forces are thought to be the cause of surface tension in liquids, of resistance to flow in fluids and of the departure of some gases from behavior predicted by the ideal gas law.

At ordinary temperatures, VAN DER WAALS' FORCES *between carbon dioxide molecules are too weak to form a solid.*

vapor \'vā-pər\ *n.*
CHEMISTRY. The gaslike substance that evaporates from a liquid at temperatures below the boiling point of the liquid.

Because gasoline VAPOR *is denser than air, it can be poured.*

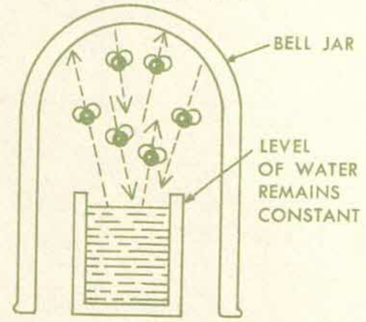
vapor density \'vā-pər 'den(t)-sət-ē\
CHEMISTRY and PHYSICS. A number expressing the weight of a given volume of a gas or vapor relative to the weight of the same volume of air or hydrogen used as a standard.

If hydrogen has a density of 2, the VAPOR DENSITY *of air is about 30 and that of pure oxygen is about 32.*

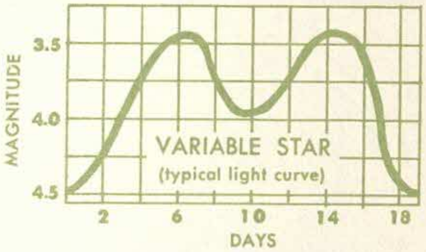
vapor pressure \'vā-pər 'presh-ər\
CHEMISTRY and PHYSICS. The pressure produced by the vapor of a specific liquid when the air holds all the vapor it can; also, the pressure of a vapor that is in equilibrium with the liquid from which it came or when no apparent evaporation is taking place. Vapor pressure increases as temperature increases.

When the VAPOR PRESSURE *of a liquid equals the pressure of the atmosphere, the liquid boils.*

Number of molecules escaping into gaseous state equals number of molecules returning to liquid



VAPOR PRESSURE
(IN EQUILIBRIUM)



VARIABLE STAR
(typical light curve)

variable \'ver-ē-ə-bəl\ *n.*

MATHEMATICS. A symbol that may assume any one of a number of values.

In the equation $x + y = 43$, x is a VARIABLE *and so is y.*

variable star \'ver-ē-ə-bəl 'stär\

ASTRONOMY. A star whose brightness varies, usually at regular periods; see *cepheid, eclipsing binary, nova* and *pulsating stars.*

The period of a VARIABLE STAR *may range from a few hours to 600 days or more.*

variable wing \'ver-ē-ə-bəl 'wiŋ\

AERONAUTICS. An aircraft wing, the sweepback angle of which can be changed by mechanical means while the plane is in the air.

One kind of VARIABLE WING *can be set in forward position for maximum lift at relatively-slow speeds, as during takeoff and landing, then swept back to reduce wind resistance during high-speed flight.*

VARIATION
(in color of guinea pig)

variation \ˌver-ē-'ā-shən\ *n.*

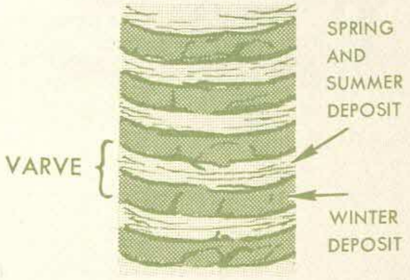
1. BIOLOGY. The difference in a particular characteristic among the offspring of a certain species or between offspring and their parents. 2. EARTH SCIENCE. The angle between the direction a compass needle points, or magnetic north, and true north; see *magnetic declination* and *agonic line.* 3. MATHEMATICS. A relationship between two variables in which a change in one variable produces a corresponding change in the other.

The degree of VARIATION *among human beings exists to the same degree among other animals and among plants.*

variety \və-'rī-ət-ē\ *n.*

BIOLOGY. An indefinite subdivision of a species, usually identifiable by one or more characteristics, such as color and disease resistance.

Pink and seedless are each a VARIETY *of grapefruit.*



varve \'värv\ *n.*

EARTH SCIENCE. A sedimentary deposit made up of pairs of thin layers. The lower layer is a coarse, sandy material, and the other layer is a fine silt or clay material. Each pair of layers represents the sediment deposited in a lake in one year.

The lower layer of VARVE *is deposited during the spring and summer months when the volume of water flowing into a lake is greatest.*

vascular system \'vas-kyə-lər 'sis-təm\

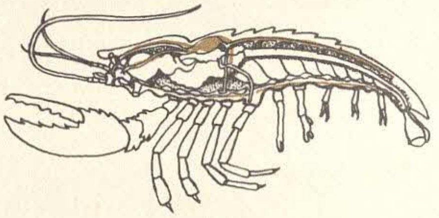
ANATOMY and BIOLOGY. Any arrangement of vessels that allows flow or circulation of liquids in an organism, as the xylem and phloem tissues in ferns and seed plants, and the blood vessels and lymphatic vessels in vertebrate animals.

The VASCULAR SYSTEM *in a tree permits the flow of water and minerals taken in through the roots and of food manufactured in the leaves and stems.*

vasomotor reflexes \ˌvas-ō-'mōt-ər 'rē-ˌfleks-əs\

PHYSIOLOGY. Nerve reactions that control the contraction or dilation of blood vessels.

Excitement or anger may stimulate VASOMOTOR REFLEXES.



VASCULAR SYSTEM
(of lobster)

vasopressor \ˌvas-ō-'pres-ər\

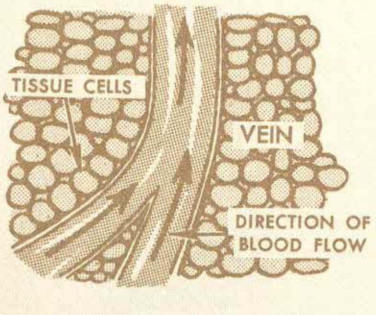
MEDICINE. An agent that raises blood pressure.

A VASOPRESSOR *may be a drug that causes the blood vessels to contract slightly.*

vector \'vek-tər\ *n.*

1. PHYSICS. A quantity having both direction and magnitude (amount), such as a force or a velocity. A vector differs from a scalar quantity in that a scalar quantity has magnitude but no direction. 2. MATHEMATICS. A line segment that has direction and magnitude. 3. MEDICINE. An organism, often an insect, that carries disease-producing organisms from one host to another.

A VECTOR *usually is represented by an arrow pointing in the direction of its action and having a length proportional to its magnitude.*



vegetable \'vej-tə-bəl\ *n.*

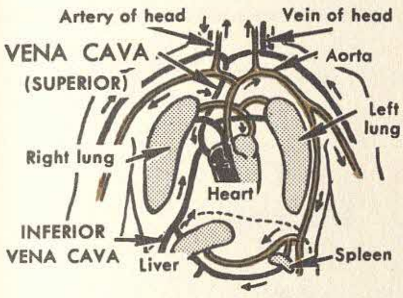
BOTANY. A general term for herbaceous plants, or parts of plants grown for food.

The carrot is a VEGETABLE *valued for its high vitamin A content.*

vein \'vān\ *n.*

1. ANATOMY and ZOOLOGY. Any of the blood vessels that return blood from the lungs or body tissues to the heart. 2. BOTANY. A bundle of xylem and phloem tissue in a leaf. 3. EARTH SCIENCE. A mineral deposit in a fissure, or crack, in a rock or rock formation; also, a zone of ore in a rock formation.

Blood from a VEIN *is darker red than is blood from an artery.*



velocity \və-'läs-ət-ē\ *n.*

PHYSICS. The speed and direction of a moving object; also, sometimes, the number of degrees a rotating or revolving object turns in one second (angular velocity).

If the VELOCITY *of an object is changed, the object is said to be accelerated.*

vena cava \'vā-nə-'käv-ə\

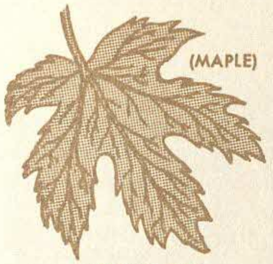
ANATOMY. The large abdominal vein (the inferior vena cava) that carries blood from organs below the diaphragm back to the heart; also, the large vein above the heart (the superior vena cava) that carries blood back to the heart from the head, neck and upper extremities.

Blood from a VENA CAVA *vein empties into the right side of the heart.*

venation \vā-'nā-shən\ *n.*

BIOLOGY. The arrangement of veins in a leaf. Venation may be parallel from base to tip, as in grass, or a net pattern, as in the blade of a maple leaf; also, the pattern of veins in insect wings.

Leaf VENATION *not only provides pathways for water, minerals and food but also provides resistance to tearing.*



VENATION

ventifact \'vent-ə-ˌfakt\ *n.*

EARTH SCIENCE. A stone with surfaces shaped by the abrasive action of wind-blown sand.

A VENTIFACT *is usually found in sandy desert areas or along beaches.*

ventral \'ven-trəl\ *adj.*

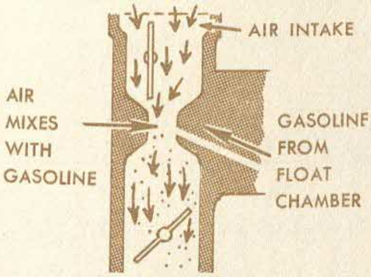
ANATOMY and BIOLOGY. Referring to the underside, or lower surface, of an organism or structure.

Hair on the VENTRAL *surface of a field mouse is usually lighter than hair on the dorsal surface.*

ventricle \'ven-tri-kəl\ *n.*

ANATOMY and ZOOLOGY. Either of the two lower chambers of the heart; also, any one of the four cavities within the brain that contain cerebrospinal fluid.

In mammals, the right VENTRICLE *pumps blood only to the lungs, while the left ventricle pumps blood to the rest of the body.*

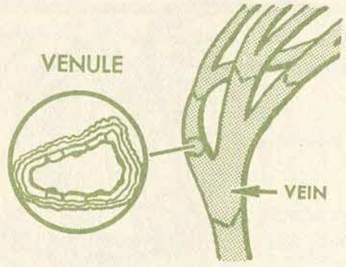


VENTURI TUBE
(in automobile carburetor)

venturi tube \ven-'tu̇(ə)r-ē 't(y)üb\

ENGINEERING and PHYSICS. A hollow tube, narrower at the middle than at the ends. As gas or liquid flows through the tube, it exerts less sideways pressure in the narrow middle section than it does near the ends. In application, the reduced sideways pressure may be used to calculate the rate of fluid flow or to cause fluids to be forced into the stream of gas or liquid; see *Bernoulli's principle.*

An automobile engine carburetor uses a VENTURI TUBE *to mix gasoline vapor with air.*



venule \'ven-(ˌ)yü(ə)l\ *n.*

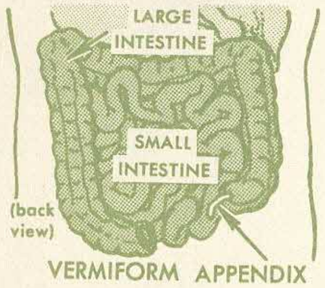
ANATOMY and ZOOLOGY. Any small vein formed by a junction of capillaries.

Blood flow in a VENULE *is faster than in a capillary but slower than in a vein.*

verifier \'ver-ə-ˌfī(-ə)r\ *n.*

ENGINEERING. A mechanical device for checking the accuracy with which data has been recorded on magnetized tape or by key punch.

A VERIFIER *can compare data on punched cards with that previously recorded on collection sheets.*



vermiform appendix \'vər-mə-ˌfȯrm ə-'pen-diks\

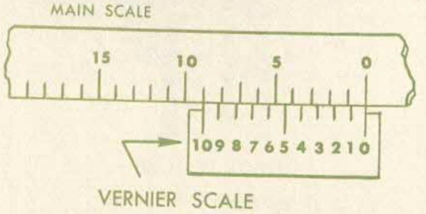
ANATOMY. A worm-shaped pouch attached at its open end to the lower side of the first part of the large intestine. It is normally from three to four inches long and serves no known function.

If an infected VERMIFORM APPENDIX *is not removed, it may rupture and spread infection throughout the abdomen.*

vernal equinox \'vərn-ᵊl 'ē-kwə-ˌnäks\

ASTRONOMY. The time of year when the sun appears directly overhead at noon to an observer at the earth's equator; also, the point at which the ecliptic and the celestial equator intersect, the sun being at this point in the heavens on approximately March 21; see *equinox.*

At the time of the VERNAL EQUINOX, *nights and days are of equal length everywhere on earth.*



vernier scale \'vər-nē-ər 'skāl\

MATHEMATICS. A short, graded auxiliary scale that slides along a longer main scale of a measuring instrument so that fractional subdivisions can be read more accurately.

A VERNIER SCALE *is commonly used to read a barometer.*

vertebra \'vərt-ə-brə\ *n.*

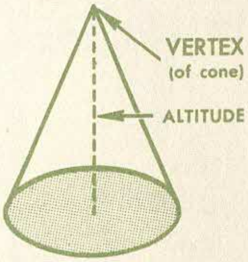
ANATOMY and ZOOLOGY. Any of the bones that make up the backbone or spinal column of vertebrate animals. They are usually separated by elastic, cartilaginous disks, and each vertebra contains an opening through which the spinal cord passes.

The axis is an important VERTEBRA *used in turning the head.*

vertebrate \'vərt-ə-brət\ *adj.*

ZOOLOGY. Referring to any organism having a backbone composed of vertebrae. Vertebrate animals include fish, amphibians, reptiles, birds and mammals.

VERTEBRATE *animals are called higher animals because of their complex body structures and well-developed nervous systems.*



vertex \'vər-ˌteks\ *n.*

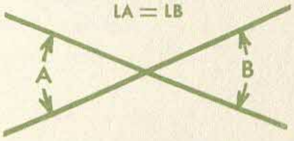
MATHEMATICS. The point that the two sides of an angle have in common; in general, the common intersection of two or more lines, whether or not they lie in the same plane.

The altitude of a cone is the perpendicular distance from its VERTEX *to its base.*

vertical angles \'vərt-i-kəl 'aŋ-gəlz\

MATHEMATICS. Two nonadjacent angles formed when two lines or two planes intersect.

If two straight lines intersect, the VERTICAL ANGLES *formed are equal.*



VERTICAL ANGLES

vertical circle \'vərt-i-kəl 'sər-kəl\

ASTRONOMY. An imaginary circle that passes through an observer's zenith (the point directly overhead) and that is perpendicular to the horizon. Vertical circles are used in locating the positions of celestial objects.

The VERTICAL CIRCLE *that passes from due north to due south is called the celestial meridian.*

vertical fault \'vərt-i-kəl 'fȯlt\

EARTH SCIENCE. A fracture of the earth's crust in which the fault plane is perpendicular, or nearly so.

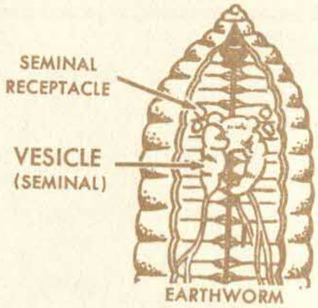
The uplift of a block of the earth's crust may result in a VERTICAL FAULT.

vesicle \'ves-i-kəl\ *n.*

1. ANATOMY and ZOOLOGY. A small cavity or sac, usually filled with fluid. 2. BOTANY. A small, air-filled chamber within a tissue. 3. EARTH SCIENCE. A small pocket or cavity found in some igne-

ous rocks, formed by the expansion of gas at the time the rock was formed.

A seminal VESICLE *in an earthworm contains stored sperm cells.*



vestigial structure \ve-'stij-(ē-)əl 'strək-chər\

BIOLOGY. An organ or part of an organism that serves no known useful function but that represents an essential organ or part in some related organism.

While the appendix is a useless VESTIGIAL STRUCTURE *in man, it is necessary to the digestive system of a rabbit.*

veterinary medicine \'vet-ə-rən-ˌer-ē 'med-ə-sən\

MEDICINE. A special branch of medicine, dealing with the diagnosis and treatment of the diseases and injuries of domestic animals.

VETERINARY MEDICINE *has controlled epidemic diseases in animals through inoculations.*

viable \'vī-ə-bəl\ *adj.*

BIOLOGY. Referring to an organism that is alive and able to continue to live in a normal manner.

A seed planted after several years of storage may still be VIABLE.

video frequency \'vid-ē-ˌō 'frē-kwən-sē\

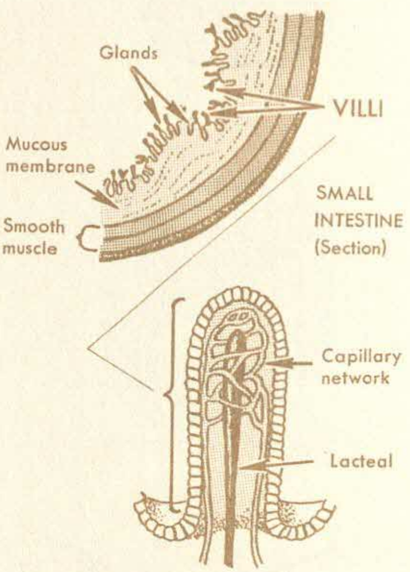
ENGINEERING. Any radio wave used to transmit the picture portion of a telecast. Video frequencies in the United States and Canada are 50 to 88, 174 to 216 and 470 to 890 megacycles per second.

Any VIDEO FREQUENCY *used by channels 2 through 13 must be in the vhf (very high frequency) range, or less than 216 megacycles per second.*

villi \'vil-ˌī\ *n.*

ANATOMY. Small, fingerlike projections on the inside lining of the small intestine. Villi function as absorption surfaces for digested food in the intestine.

VILLI *greatly increase the surface area of the lining of the small intestine.*



vinyl plastic \'vīn-ᵊl 'plas-tik\

CHEMISTRY. A class of plastic materials that soften when heated; any polymer whose molecules contain many vinyl groups ($CH_2{=}CH-$).

A VINYL PLASTIC *such as polyvinyl chloride is resistant to most common chemicals.*

VINYL PLASTIC

viosterol \vī-ˈäs-tə-ˌrȯl\ *n.*

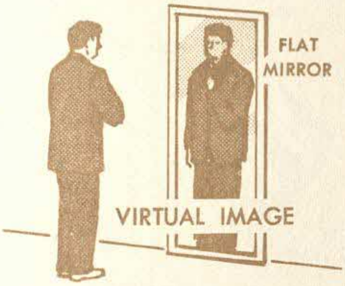
CHEMISTRY. One of the D vitamins.

VIOSTEROL *may help prevent rickets in infants.*

virtual image \ˈvərch-(ə-)wəl ˈim-ij\

PHYSICS. An image that can be seen but that cannot be projected on a screen. A virtual image is formed by light that seems to come from a place that it does not come from and is distinguished from a real image that can be projected on a screen.

When looking into a flat mirror, one sees a VIRTUAL IMAGE *that seems to be located behind the mirror.*



virulent \ˈvir-(y)ə-lənt\ *adj.*

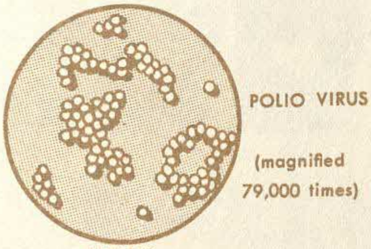
BIOLOGY and MEDICINE. Referring to extremely pathogenic microorganisms, usually bacteria or viruses, that rapidly break down the natural defenses of a host organism; also, referring to a disease or infection caused by such organisms.

The virus that causes poliomyelitis is often VIRULENT.

virus \ˈvī-rəs\ *n.*

BIOLOGY and MEDICINE. A noncellular, submicroscopic particle that lives in the cells of plants and animals. A single virus consists of a nuclear protein core surrounded by protein and may be an intermediate form of matter between the living and nonliving.

Outside a cell, a VIRUS *may form part of an apparently-nonliving crystal, while within a cell it may reproduce, as do living organisms.*



VIRUS

viscera \ˈvis-(ə)ra\ *n.*

ANATOMY and ZOOLOGY. All the organs contained in the chest and abdominal cavities.

The VISCERA *include such organs as the lungs, heart, kidneys, stomach, liver and intestines.*

viscose \ˈvis-ˌkōs\ *n.*

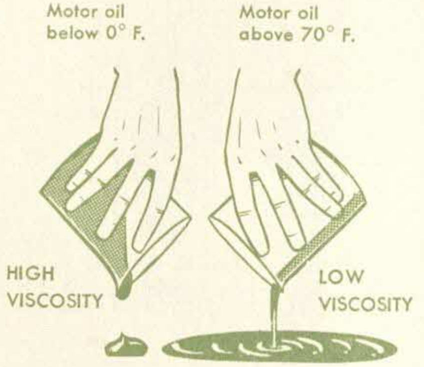
CHEMISTRY. A syruplike liquid produced by chemical treatment of cellulose fibers. Viscose may be made into fibers (rayon) or into thin sheets (cellophane).

Rayon fibers are formed by forcing VISCOSE *through small pinholes into a dilute solution of sulfuric acid.*

viscosity \vis-ˈkäs-ət-ē\ *n.*

CHEMISTRY and PHYSICS. Resistance to flow or an apparent force that prevents fluids from flowing easily. Viscosity is especially noticeable in such liquids as oil and syrup.

The VISCOSITY *of most liquids is decreased by increasing their temperatures.*


Motor oil below 0° F.
Motor oil above 70° F.
HIGH VISCOSITY
LOW VISCOSITY

VISCOSITY

visible spectrum \'viz-ə-bəl 'spek-trəm\

PHYSICS. An array of those wavelengths (colors) of electromagnetic radiation that can be seen by man. It is composed of wavelengths between 3,900 angstroms (violet) and 7,000 angstroms (red).

Radiation from the sun includes some wavelengths that are not in the VISIBLE SPECTRUM *but that may be detected by man as heat.*

visual angle \'vizh-(ə-)wəl 'aŋ-gəl\

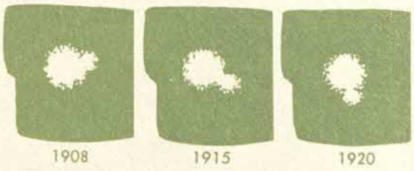
ASTRONOMY. The apparent size of a celestial object as measured by the angle formed between light rays coming from the extremities of the object to the eye.

Since the moon, although smaller, is nearer the earth than the sun, both the moon and the sun have a VISUAL ANGLE *of about ½ degree.*

visual binary \'vizh-(ə-)wəl 'bī-nə-rē\

ASTRONOMY. A pair of stars, called binary stars, that are far enough apart to be observed through a telescope as separate. As in the case of all binary stars, the two stars revolve around a common center of mass under the influence of mutual gravitational attraction; see *binary stars.*

By the use of relatively-large telescopes with adequate resolving power, Sirius and its companion star can be observed as a VISUAL BINARY.



VISUAL BINARY
(KRUEGER 60)

visual purple \'vizh-(ə-)wəl 'pər-pəl\

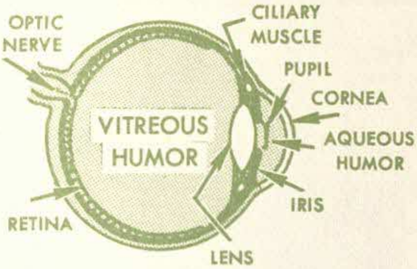
PHYSIOLOGY and ZOOLOGY. A reddish-purple, photosensitive pigment found in the rods of the retina; also called rhodopsin.

The cones of the retina contain a pigment called iodopsin that is similar to VISUAL PURPLE.

vitamin \'vīt-ə-mən\ *n.*

BIOLOGY. Any of a large number of organic substances present in small quantities in plant tissues and necessary to normal nutrition and the well-being of organisms. Vitamins are manufactured by plants but must be ingested by animals.

Thiamine, a VITAMIN *found in the seed coatings of rice and other plants, is essential to the health of the nervous system of animals.*



vitreous \'vi-trē-əs\ *adj.*

1. CHEMISTRY. Referring to any substance that has glasslike characteristics; also, sometimes, referring to a solid substance composed of such small crystals that it appears to be noncrystalline. 2. EARTH SCIENCE. Referring to minerals such as quartz and calcite that have a glasslike luster.

A VITREOUS *enamel coating is used on most household refrigerators.*

vitreous humor \'vi-trē-əs 'hyü-mər\

ANATOMY. The clear, jellylike substance that fills the cavity in the eyeball between the lens and the retina.

In man, the VITREOUS HUMOR *makes up about ⅘ of the total volume of the eyeball.*

VIVARIUM

vivarium \vī-'var-ē-əm\ *n.*

BIOLOGY. A small enclosure, usually with glass sides, in which small living plants, animals, or both, are maintained; an aquarium or terrarium.

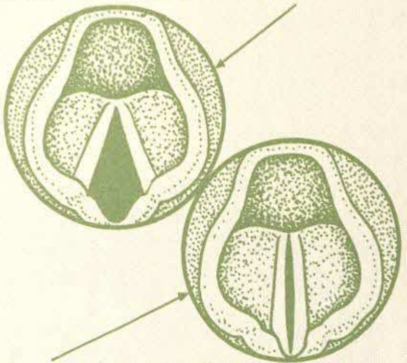
Special temperature and humidity controls may be necessary for a tropical-animal VIVARIUM.

viviparous \vī-'vip-(ə-)rəs\ *adj.*

ZOOLOGY. Referring to the reproductive pattern in which young are born alive instead of hatched from incubated eggs; see *oviparous.*

All mammals are VIVIPAROUS.

Vocal cords relaxed so that air passes them without producing sound



Cords tensed so they vibrate and produce sound, as in speech

VOCAL CORDS VIEWED THROUGH LARYNGOSCOPE

vivisection \ˌviv-ə-'sek-shən\ *n.*

MEDICINE and PHYSIOLOGY. The process of operating on live animals to acquire pathological or physiological information.

VIVISECTION *has yielded knowledge valuable in the medical diagnosis and treatment of human disease.*

vocal cords \'vō-kəl 'kȯ(ə)rdz\

ANATOMY. Either of two pairs of folds in the larynx, consisting of white, fibrous bands. The lower pair produces sounds when vibrated by air passing between the folds.

Voice pitch is controlled by the tension of the VOCAL CORDS.

volatile \'väl-ət-ᵊl\ *adj.*

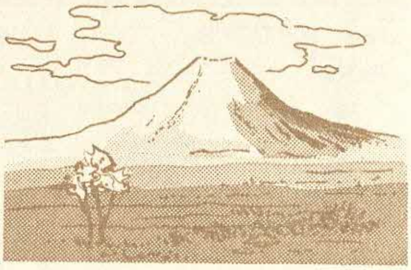
CHEMISTRY. Referring to a substance that evaporates readily at ordinary temperatures.

*Ether, a highly-*VOLATILE *compound, is used as an anesthetic.*

volcanic cone \väl-'kan-ik 'kōn\

EARTH SCIENCE. A cone-shaped mound built by volcanic eruption and composed of deposits of cinders, of lava or of both; see *cinder cone* and *shield volcano.*

The shape of a VOLCANIC CONE *is determined by how fast and how long the volcano erupts and the kind of material ejected.*



VOLCANIC CONE

volcanic neck \väl-'kan-ik 'nek\

EARTH SCIENCE. A plug or column of solidified lava that fills the main vent of an extinct volcano.

A VOLCANIC NECK *may be exposed because of differing rates of erosion of the neck itself and the rock material that surrounds it.*

volcano \väl-'kā-(ˌ)nō\ *n.*

EARTH SCIENCE. An opening or vent in the earth's surface through which molten rock is flowing or has flowed; also, sometimes, both the vent and the cone surrounding it.

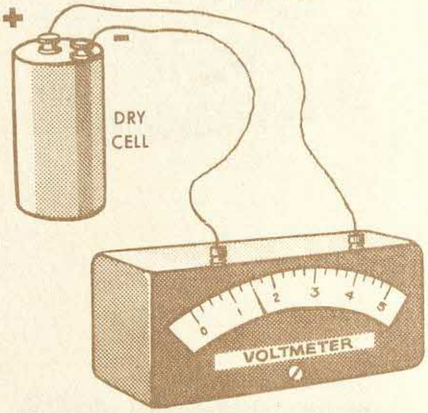
A VOLCANO *may begin with a violent explosion or with lava flowing quietly from the earth.*

volt \'vōlt\ *n.*

PHYSICS. A unit of electrical force equal to that amount of electromotive force that will cause a steady current of one ampere to flow through a resistance of one ohm; see *potential difference, ohm, electromotive force* and *ampere.*

An ordinary flashlight cell produces a potential difference of more than one VOLT.

VOLTAGE



voltage \'vōl-tij\ *n.*

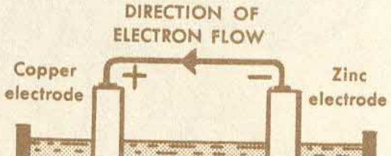
PHYSICS. The amount of electromotive force, measured in volts, that exists between two given points; see *volt.*

In order to cause a spark to jump between two points one inch apart in air, there must be a VOLTAGE *of more than 25,000 volts between them.*

voltage regulator \'vōl-tij 'reg-yə-ˌlāt-ər\

ENGINEERING and PHYSICS. A device that produces a nearly-constant electrical voltage, even though the source of electrical power may have a varying voltage.

A VOLTAGE REGULATOR *in an automobile controls the generator voltage used to charge the storage battery.*

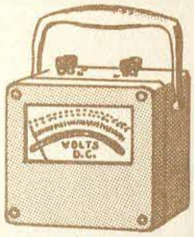


VOLTAIC CELL

voltaic cell \väl-'tā-ik 'sel\

CHEMISTRY and PHYSICS. A device that produces electricity from chemical reactions. In simple form, it consists of two plates of different metals partly submerged in a liquid (electrolyte) that conducts an electric current. Electricity is obtained from the cell by using a wire to connect the dry parts of the metal plates.

A VOLTAIC CELL *can be made by placing a silver spoon and an iron nail (not touching) in a glass half full of vinegar.*

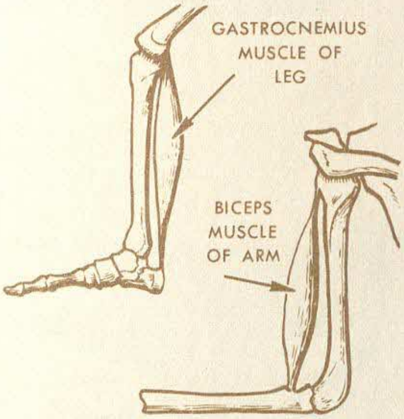


VOLTMETER

voltameter \vōl-'tam-ət-ər\ *n.*

CHEMISTRY and PHYSICS. A device used to measure the amount of electric current that passes by a given point, as distinguished from a voltmeter, which measures potential difference. It utilizes a chemical reaction, such as the plating of metal from a solution or the breakdown of water (electrolysis) into hydrogen and oxygen, and measures the product of the reaction.

In a gas VOLTAMETER, *glass tubes are used to collect and measure the gas produced by electrolysis.*



VOLUNTARY MUSCLES

volt-ampere \vōl-'tam-ˌpi(ə)r\ *n.*

ENGINEERING and PHYSICS. A unit of measure for alternating electric currents. It is approximately the same as a watt; see *watt.*

In dealing with direct current, a VOLT-AMPERE *and a watt are the same.*

voltmeter \'vōlt-ˌmēt-ər\ *n.*

PHYSICS. An instrument used to measure the difference in electrical potential (voltage) between two points; see *potential difference.*

If two objects are equally charged, a VOLTMETER *will register zero potential difference when connected to them.*

volume \'väl-yəm\ *n.*

1. MATHEMATICS and PHYSICS. The space taken up by a solid, liquid or gas, measured in cubic units. 2. ENGINEERING and PHYSICS. The loudness of a series of sounds, or the intensity of an electrical signal in an electronic device that produces sound.

The VOLUME *of a box 4 inches long, 3 inches wide and 2 inches deep is 24 cubic inches.*

V-SHAPED VALLEY

voluntary muscles \'väl-ən-ˌter-ē 'məs-əlz\

ANATOMY. The muscles of the body normally subject to conscious control, such as the skeletal muscles; see *striated muscles.*

In a reflex action, VOLUNTARY MUSCLES *may function involuntarily.*

V-shaped valley \'vē-shāpt 'val-ē\

EARTH SCIENCE. A depression or gorge with relatively-steep sides and a narrow floor, whose cross section resembles the letter V. It is the product of a downcutting stream.

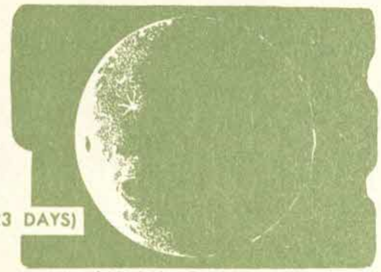
The Grand Canyon is a V-SHAPED VALLEY *that, in some places, is 15 miles wide and over a mile deep.*

W

waning moon \'wān-iŋ 'mün\

ASTRONOMY. The moon as seen from the earth during the period between full moon and new moon; see *waxing moon.*

The crescent of the WANING MOON *becomes thinner as the moon approaches the phase of new moon.*



WANING MOON

warm air mass \'wȯ(ə)rm 'a(ə)r 'mas\

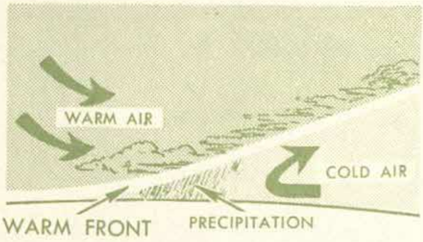
EARTH SCIENCE. A large body of air that is warmer than the surface over which it passes or is warmer than nearby air masses.

Low clouds and rain usually accompany the arrival of a WARM AIR MASS.

warm-blooded \'wȯ(ə)rm-'bləd-əd\ *adj.*

ZOOLOGY. Referring to animals whose body temperatures remain fairly constant and are often higher than the usual temperatures of their environments; also called homoiothermic.

Mammals and birds are WARM-BLOODED, *while fish, reptiles and amphibians are cold-blooded.*



warm front \'wȯ(ə)rm 'frənt\

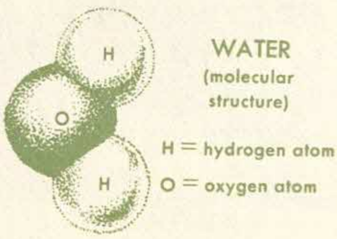
EARTH SCIENCE. The gently-sloping boundary layer between an advancing warm air mass and an air mass of lower temperature.

Cirrus clouds followed by lower stratus clouds often indicate an approaching WARM FRONT.

warping \'wȯ(ə)rp-iŋ\ *n.*

EARTH SCIENCE. The bending of a large area, normally involving hundreds of square miles of the earth's crust, by massive and gradual underground pressures. Warping may elevate or lower broad areas over long periods of time.

The presence on land of large areas of sedimentary rock containing marine fossils often indicates that WARPING *has raised the land from the sea.*



water \'wȯt-ər\ *n.*

CHEMISTRY. H_2O. In its pure form, and at temperatures between 0° C. and 100° C., an odorless and tasteless liquid. It is a compound of hydrogen and oxygen that will dissolve many other substances. Its freezing point is 0° C. and its boiling point

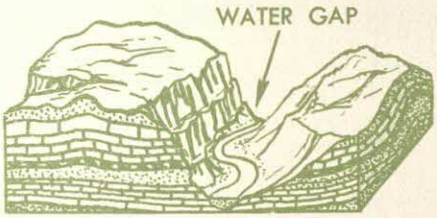
100° C. Water weighs one gram per cubic centimeter at 4° C. and occurs on earth as a liquid, gas (water vapor) and solid (ice).

In order for any planet to sustain life as we know it, it must have a supply of WATER.

water clock \'wȯt-ər 'kläk\

ENGINEERING. A device that measures time by the flow of water.

People in ancient civilizations used devices like the WATER CLOCK *and sundial to measure time.*



water cycle \'wȯt-ər 'sī-kəl\

EARTH SCIENCE. The constant process in which water evaporates from the surface of oceans, lakes, ground plants and animals, rises in the atmosphere, condenses and falls back to the earth in the form of precipitation.

The sun is the source of energy that maintains the earth's WATER CYCLE.

water gap \'wȯt-ər 'gap\

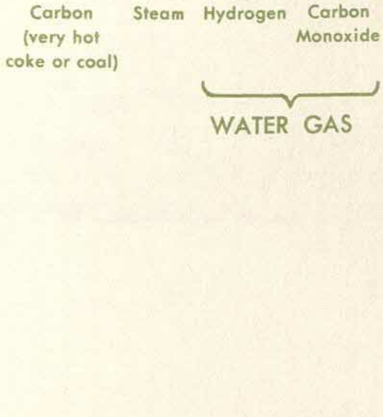
EARTH SCIENCE. A pass through a mountain ridge cut by a stream flowing across the land as the mountain was formed.

In mountainous areas, roads and railroads are often built along the stream in a WATER GAP.

water gas \'wȯt-ər 'gas\

CHEMISTRY. A mixture of gases produced by forcing steam through very hot coke or coal. It is a mixture of carbon monoxide and hydrogen with small amounts of nitrogen and carbon dioxide and is sometimes used as a fuel for heating and cooking.

The heat value of WATER GAS *is frequently increased by adding hydrocarbon gases, such as butane and propane.*



$$\underset{\substack{\text{Carbon}\\\text{(very hot}\\\text{coke or coal)}}}{C} + \underset{\text{Steam}}{H_2O} \longrightarrow \underbrace{\underset{\text{Hydrogen}}{H_2} + \underset{\substack{\text{Carbon}\\\text{Monoxide}}}{CO}}_{\text{WATER GAS}}$$

water glass \'wȯt-ər 'glas\

CHEMISTRY. A solution of sodium silicate and water that forms a thick, viscous liquid used in making detergents and adhesives and for fireproofing fabrics.

WATER GLASS *has been used to preserve eggs by coating the shell and sealing the pores.*

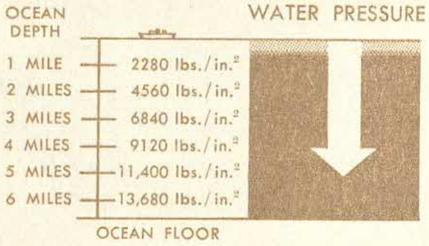
water injection \'wȯt-ər in-'jek-shən\

AERONAUTICS and ENGINEERING. The introduction of water into the fuel and air mixture of certain internal combustion engines, resulting in increased power or thrust. In piston-type engines, it results in a cooling of the compressed fuel-air mixture, and in jet engines, it also increases the mass of the escaping gases, thus increasing thrust.

The engines of many jet aircraft are equipped with WATER INJECTION *to increase thrust and make possible the use of shorter runways for takeoffs.*

water of crystallization \'wȯt-ər əv ˌkris-tə-lə-'zā-shən\
CHEMISTRY. The water that is combined in many, but not all, crystals. It can be removed by heating. When removed, the crystal loses its apparent crystalline properties and has the appearance of a powder; also called water of hydration.

A substance containing WATER OF CRYSTALLIZATION *in a formula is usually represented by a dot separating the substance from the water it contains, such as* $FeSO_4 \cdot 7H_2O$ *and* $CuSO_4 \cdot 5H_2O$.



water of hydration \'wȯt-ər əv hī-'drā-shən\
CHEMISTRY. Water of crystallization. See *water of crystallization.*

water pressure \'wȯt-ər 'presh-ər\
ENGINEERING and PHYSICS. The force exerted by water on a given area of an object, depending on the depth of the water. It is measured in such units as pounds per square inch.

Under the sea, WATER PRESSURE *increases at a rate of 1.14 tons per square inch for every mile of depth.*

watershed \'wȯt-ər-ˌshed\ *n.*
EARTH SCIENCE. The entire drainage region that supplies water to a lake or river; also called drainage basin.

Dams and reservoirs constructed in a nearby WATERSHED *are used as water sources for some cities.*

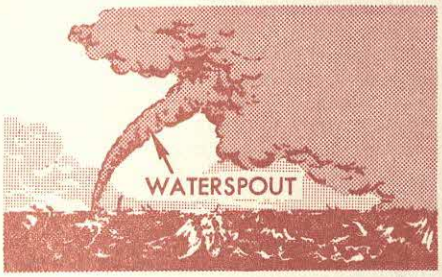
water softening \'wȯt-ər 'sȯf-(ə-)niŋ\
CHEMISTRY. The chemical treatment of hard water so that it will form suds with soap more easily. Water softening involves removal or inactivation of calcium and magnesium ions from the hard water.

WATER SOFTENING *may be done by removing calcium and magnesium ions or by adding chemicals, such as washing soda and borax, that react with the calcium and magnesium ions.*

waterspout \'wȯt-ər-ˌspau̇t\ *n.*
EARTH SCIENCE. A funnel-shaped cloud, or tornado, that occurs over a body of water. The cloud develops from a cumulonimbus

and may extend to the water surface, drawing water droplets up into the cloud.

A WATERSPOUT *is more likely to occur in the tropics than in the temperate and frigid zones.*



water table \'wȯt-ər 'tā-bəl\

EARTH SCIENCE. That level beneath the ground surface below which ground water fills all spaces and saturates all permeable matter. A water table is variable and uneven but is generally parallel to the ground surface.

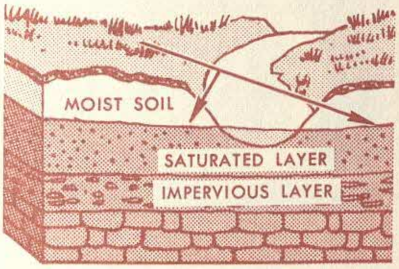
A body of water develops at the point where a WATER TABLE *meets the ground surface.*

water vapor \'wȯt-ər 'vā-pər\

EARTH SCIENCE. Water in the gaseous state. It is an important part of the atmosphere. The amount suspended in the atmosphere varies with temperature, since warm air can hold more than cooler air; see *relative humidity.*

As warm, moist air rises and is cooled, it loses its WATER VAPOR *through condensation.*

WATER TABLE



watt \'wät\ *n.*

PHYSICS. A unit of power equal to 1/746 horsepower or one joule per second. It is used in both electricity and mechanics. In electricity, it is the power produced when one ampere of current flows between two points that have a potential difference of one volt.

The work done by one WATT *acting for one hour is called a watt-hour.*

watt-hour \'wät-'au̇(ə)r\ *n.*

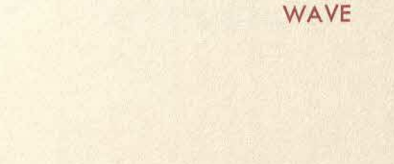
PHYSICS. The total amount of energy used in one hour by a device that uses one watt of power for continuous operation.

Electrical energy is usually sold by the WATT-HOUR *or the kilowatt-hour (1,000 watt-hours).*

wave \'wāv\ *n.*

1. PHYSICS. A disturbance that passes through or over a given medium but that causes no permament change in the medium or in its position. The term is often used in describing sound, light, alternating electric current and mechanical disturbances. 2. EARTH SCIENCE. A disturbance caused by earthquakes or man-made explosions that travels through the earth in two principal forms, compressional waves and transverse waves.

A WAVE *is usually considered to have velocity, amplitude and length.*

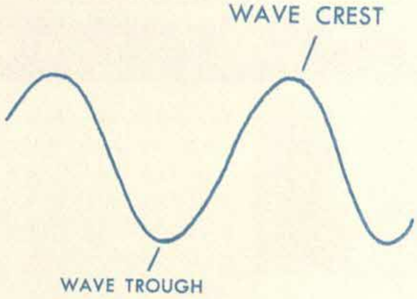


WAVE

wave crest \'wāv 'krest\

EARTH SCIENCE and PHYSICS. That part of a wave in which the disturbance is most intense in a positive direction; also, in a water wave, that part that is highest above the normal surface of the water.

The distance between a WAVE CREST *and the normal surface of the water is called the amplitude of the wave.*



waveform \'wāv-ˌfo̊(ə)rm\ *n.*

ENGINEERING and PHYSICS. A shape or line that usually follows a cyclic curve and that represents the condition of some medium through which waves are passing, at one instant of time.

The pattern that appears on a graph when alternating electrical current is plotted (amplitude against time) is a regularly-repeated WAVEFORM.

wave frequency \'wāv 'frē-kwən-sē\

PHYSICS. The number of waves that pass a given point in a given time, usually expressed in cycles (waves) per second.

The WAVE FREQUENCY *of any wavelike disturbance is equal to its speed divided by its length.*

wave front \'wav 'frənt\

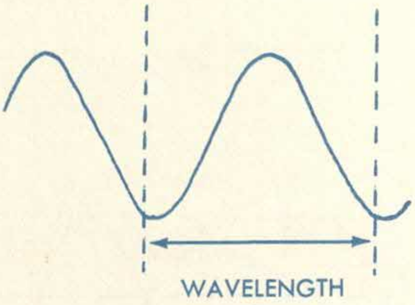
EARTH SCIENCE and PHYSICS. The leading edge of a wave.

A wave caused by dropping a stone in water has a WAVE FRONT *that is an expanding circle.*

wavelength \'wāv-ˌleŋ(k)th) *n.*

PHYSICS. The distance between two successive waves, usually measured from one wave crest to the next. Wavelength is equal to the velocity of a wave divided by its frequency.

The WAVELENGTH *of light is frequently measured in angstrom units (one meter equals 10,000 million angstroms).*



wave mechanics \'wāv mi-'kan-iks\

PHYSICS. A theory in which subatomic particles, such as electrons and protons, are pictured as having wave properties.

Electrons exhibit wave characteristics that have been explained only in terms of WAVE MECHANICS.

wave period \'wāv 'pir-ē-əd\

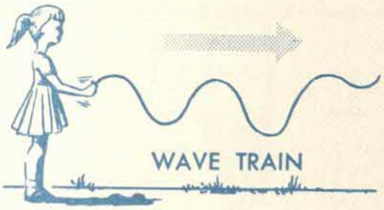
PHYSICS. The time interval between the beginning of one wave and the beginning of the following wave.

One WAVE PERIOD *is equal to one divided by the wave frequency.*

wave theory of light \'wāv 'thē-ə-rē əv 'līt\

PHYSICS. A theory that pictures light and other electromagnetic radiation as having the characteristics of wave motion.

The WAVE THEORY OF LIGHT *has been used successfully in explaining refraction and interference of light.*



wave train \'wāv 'trān\

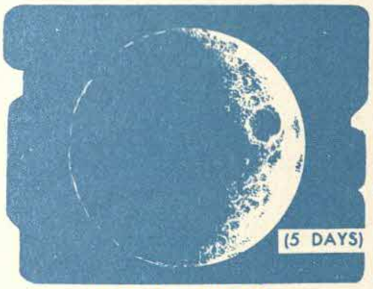
PHYSICS. A series of waves, each of which has the same properties of velocity, intensity (amplitude) and length.

A WAVE TRAIN *can be sent along a rope by rapidly shaking one end of the rope back and forth.*

wave trough \'wāv 'trȯf\

EARTH SCIENCE and PHYSICS. That part of a wave in which the disturbance is greatest but in a direction opposite to the crest of the wave; also, in a water wave, that point that is farthest below the normal water surface.

A WAVE TROUGH *occurs in a wave train midway between two successive wave crests.*



WAXING MOON

wax \'waks\ *n.*

CHEMISTRY. Any one of many compounds, or mixtures of compounds, that are insoluble in water. Wax has a glossy appearance and melts or softens at temperatures between 40° C. and 90° C. It is a complex mixture of compounds of carbon, hydrogen and oxygen and may be obtained from petroleum, plants or animals.

Carnauba WAX, *widely used in furniture and floor polishes, is obtained from the leaves of a South American palm tree.*

waxing moon \'wak-siŋ 'mün\

ASTRONOMY. The moon as seen from the earth during the period between new moon and full moon; see *waning moon.*

The crescent of the WAXING MOON *becomes thicker as the moon approaches the first-quarter phase.*

WEATHER BALLOON

weather balloon \'weth-ər bə-'lün\

EARTH SCIENCE. A lighter-than-air apparatus designed to carry instruments and radio equipment into the upper air; see *radiosonde.*

Information obtained by use of a WEATHER BALLOON *is used in long-range weather forecasting.*

weathering \'wet͟h-ə-riŋ\ *n.*

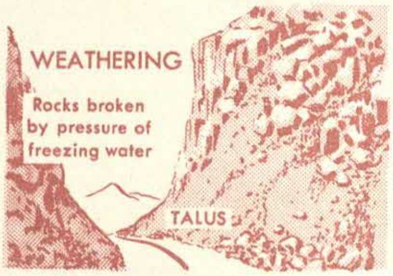
EARTH SCIENCE. The disintegration and decomposition of rocks and minerals by mechanical and chemical processes.

The freezing of water in small cracks in rocks is one cause of mechanical WEATHERING.

weather map \'wet͟h-ər 'map\

EARTH SCIENCE. A map of a large area on which the following data are usually plotted: pressure, temperature, dew point, visibility, wind direction and speed, cloud types and height of cloud base, present weather, weather during the past six hours, and pressure changes during the past three hours. Weather bureau maps are plotted every six hours and then analyzed and used for weather forecasting.

The daily WEATHER MAP *that appears in many newspapers is not so complete as an official weather bureau map, but it does show the major weather conditions affecting the area.*


WEATHERING
Rocks broken by pressure of freezing water
TALUS

weather satellite \'wet͟h-ər 'sat-ᵊl-ˌīt\

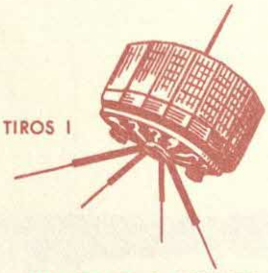
ASTRONAUTICS and EARTH SCIENCE. An artificial earth satellite designed to photograph weather conditions on earth and relay the pictures back to the earth; see *satellite.*

The world's first WEATHER SATELLITE, *Tiros I, was launched by the United States in April 1960.*

weight \'wāt\ *n.*

PHYSICS. The amount of gravitational force acting on a body, measured in absolute units of force, as pounds, or gravitational units of force equal to the mass of the body, as pounds-weight.

The WEIGHT *of an object on the moon would be one-sixth its earth weight.*



WEATHER SATELLITE

weightlessness \'wāt-ləs-nəs\ *n.*

ASTRONAUTICS. Zero gravity. See *zero gravity.*

weld \'weld\ *v.*

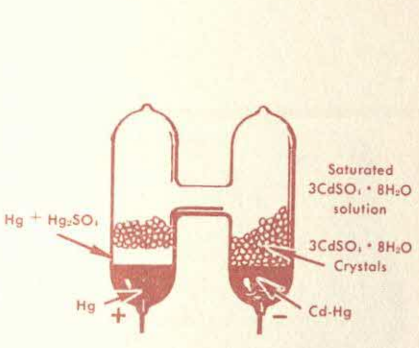
ENGINEERING. To join two pieces of metal, either by placing molten metal between the pieces to be joined and allowing it to cool and solidify or by partially melting the pieces and pressing them together.

Much research has been conducted to find a good method to WELD *aluminum and steel.*

Weston cell \'wes-tən 'sel\

PHYSICS. A device that produces a constant voltage (potential difference) from a given combination of chemical reactions. It is used as a laboratory standard for comparison with unknown voltages and produces 1.018636 volts at 20° C.

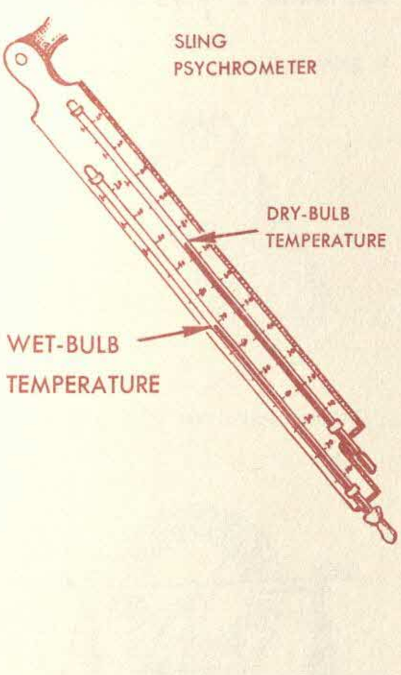
The voltage of a WESTON CELL *is not greatly affected by small temperature changes.*


Saturated $3CdSO_4 \cdot 8H_2O$ solution
Hg + Hg_2SO_4
$3CdSO_4 \cdot 8H_2O$ Crystals
Hg
+
−
Cd-Hg

WESTON CELL

wet-bulb temperature \'wet-ˌbəlb 'tem-pər-ˌchu̇(ə)r\
EARTH SCIENCE. Temperature as indicated on a thermometer that has a piece of wet cloth around its bulb. By comparing this temperature with the dry-bulb, or standard thermometer, temperature and using appropriate tables, the relative humidity can be determined; see *hygrometer* and *psychrometer.*

WET-BULB TEMPERATURE *is less than dry-bulb because of the cooling effect of evaporating water.*



wet cell \'wet 'sel\
PHYSICS. A device for producing electrical energy from chemical reactions. In a simple form, it is constructed of two plates (electrodes) of different metals partly submerged in a liquid solution that conducts electricity.

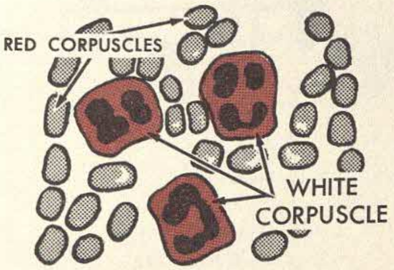
If a copper plate and a zinc plate are used as electrodes in a WET CELL, *the copper is always positive and the zinc negative.*

wetting agent \'wet-iŋ 'ā-jənt\
CHEMISTRY and PHYSICS. Any substance that decreases the surface tension of a liquid in which it is dissolved; see *detergents* and *surface tension.*

Antifreeze, which contains a WETTING AGENT, *alcohol, may leak from a radiator that is otherwise watertight.*

white \'hwīt\ *adj.*
PHYSICS. Referring to the color of an object that reflects all colors (wavelengths) of light equally well; also, referring to the color of direct sunlight at noon on a clear day; also, sometimes, referring to sound that has a uniform distribution of energy over all audible frequencies.

WHITE *light when passed through a colorless glass prism, can be separated into a spectrum of colors ranging from red to blue.*



white corpuscle \'hwīt 'kȯr-ˌpəs-əl\
PHYSIOLOGY. Any one of a number of colorless blood cells varying in size, shape, structure and function and formed chiefly in the red bone marrow and lymphatic tissue; see *leucocyte.*

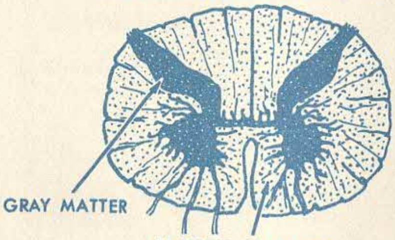
One kind of WHITE CORPUSCLE *destroys bacteria by engulfing and digesting them, while another kind aids in tissue repair.*

white matter \\'hwīt 'mat-ər\\

ANATOMY and PHYSIOLOGY. Groups of nerve fibers that serve as conductors of nerve impulses within the brain and spinal cord; see *gray matter.*

The WHITE MATTER *of the spinal cord surrounds a central core of gray matter.*

Transverse Section of Spinal Cord



white noise \\'hwīt 'nȯiz\\

PHYSICS. An electronically-produced mixture of sounds of widely-varying frequencies.

WHITE NOISE *corresponds with white light, which is a mixture of different colors.*

whole number \\'hōl 'nəm-bər\\

MATHEMATICS. An integer or any number, such as 2, 53 or 144, that is not a fraction.

If two whole numbers are added or multiplied, the result is another WHOLE NUMBER.

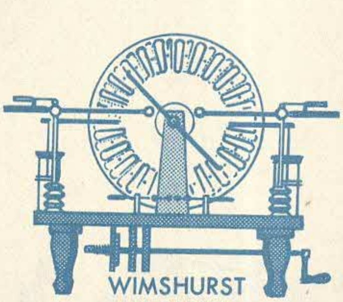
Wien's laws \\'vēnz 'lȯz\\

PHYSICS. A series of statements that describe the relationships between the temperature of an energy-radiating object and the frequencies of the energy radiated.

It is possible to determine the temperature of a star by observing its color and applying WIEN'S LAWS.

Wilson cloud chamber \\'wil-sən 'klau̇d 'chām-bər\\

PHYSICS. A cloud chamber. See *cloud chamber.*



WIMSHURST MACHINE

Wimshurst machine \\'wimz-hərst mə-'shēn\\

PHYSICS. A device used to generate static electricity. It consists of two glass or plastic disks mounted side by side, each having a series of metallic strips that contact fixed brushes. When the disks turn in opposite directions, a static charge is produced, which is stored in two capacitors and may discharge in a spark between two metal knobs attached to the capacitors.

The static charge generated by a WIMSHURST MACHINE *may be as high as 50,000 volts.*

wind \\'wind\\ *n.*

EARTH SCIENCE. Any detectable, natural and, usually, horizontal movement of air. Wind is caused by unequal heating of air masses, resulting in high and low pressure areas. Wind speed and direction (from high to low) are influenced by differences in pressure and rotation of the earth.

A WIND *is always designated by the direction from which it comes, as a "south wind."*

WIND EROSION

wind erosion \'wind i-'rō-zhən\

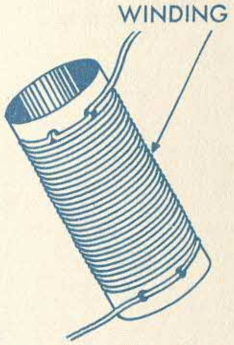
EARTH SCIENCE. The removal, transportation and deposition of rock and soil particles by wind.

WIND EROSION *is most noticeable in arid regions.*

wind gap \'wind 'gap\

EARTH SCIENCE. A dry stream valley that cuts across a ridge or mountain, formed when the headwaters of a stream that formed a water gap have been captured or diverted; also called an air gap.

A WIND GAP, *like a water gap, is often used as a roadway across a mountain ridge.*



TUNING COIL FOR CRYSTAL RADIO

winding \'wīn-diŋ\ *n.*

ENGINEERING. A system of wire loops forming a coil in various electrical devices, as a coil of a transformer, electric motor or electromagnet.

If a transformer overheats, the insulation may burn or melt from the WINDING *and cause a short circuit.*

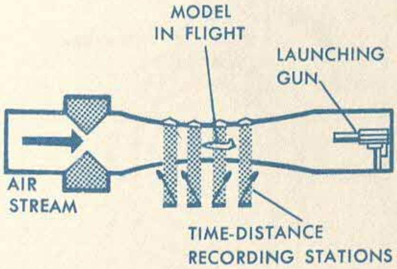
windpipe \'win(d)-ˌpīp\ *n.*

ANATOMY and ZOOLOGY. The trachea. See *trachea.*

winds aloft map \'win(d)z ə-'lȯft 'map\

AERONAUTICS and EARTH SCIENCE. A type of weather map indicating the direction and speeds of winds at altitudes at which airplane flights are made.

A WINDS ALOFT MAP *is used in planning aircraft flights.*



WIND TUNNEL
(SUPERSONIC)

wind tunnel \'wind 'tən-ᵊl\

AERONAUTICS. A large, hollow, usually-cylindrical device within which a high-speed wind is produced. It is used for passing an airstream over a stationary aircraft, aircraft model or aircraft surface.

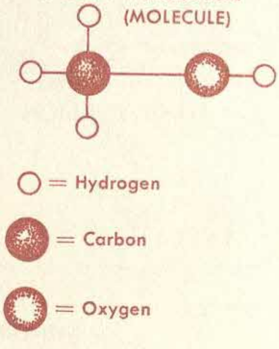
Most commercial airplane designs are tested in a WIND TUNNEL *before the aircraft are flown.*

withdrawal symptoms \wit͟h-'drȯ(ə-)l 'sim(p)-təmz\
MEDICINE. Reactions produced by depriving a person of a drug to which he is addicted.

Dizziness, nausea, sweating and depression are WITHDRAWAL SYMPTOMS *usually experienced by the addict deprived of heroin.*

wolfram \'wu̇l-frəm\ *n.*
CHEMISTRY. By international agreement, the accepted name for the element tungsten. See *tungsten.*

WOOD ALCOHOL
(MOLECULE)



wood alcohol \'wu̇d 'al-kə-ˌhȯl\
CHEMISTRY. CH$_3$OH. A colorless, poisonous liquid once produced by destructive distillation of wood but now produced synthetically by combining hydrogen and carbon monoxide. It is used in the synthesis of formaldehyde and dyes, in antifreeze and as a shellac solvent; also called methanol and methyl alcohol.

WOOD ALCOHOL *is synthesized under high pressure and in the presence of a catalyst at temperatures around 300°.*

work \'wərk\ *n.*
PHYSICS. Energy transferred from one object to another, measured by multiplying the force acting times the distance the object moves while the force is applied. Amounts of work are expressed in such units as foot-pound, joule and erg.

If an object moves 5 feet while a force of 2 pounds acts on it, 10 foot-pounds of WORK *is done.*

WORKER

HONEYBEE

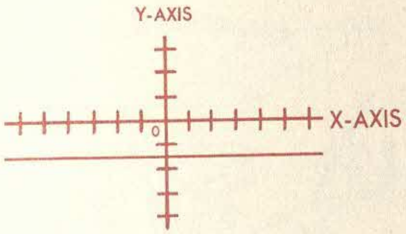
worker \'wər-kər\ *n.*
ZOOLOGY. A nonreproducing member of an insect society, usually characterized by such an activity as food gathering.

Among ants and bees, a WORKER *does not begin its duties until it becomes an adult.*

world calendar \'wər(-ə)ld 'kal-ən-dər\
ASTRONOMY. Any one of several calendar reforms that have been proposed because of our present calendar's disadvantages, such as the fact that a given day of the month falls on a different day of the week in succeeding years. One plan divides the standard 12-month year into four quarters, each containing an equal number of days. Another plan involves the establishment of 13 months, each with 28 days.

In either of the two most significant plans for a WORLD CALENDAR, *it would be necessary to have a World Day (neither a day of a week nor a month) each year and two World Days in Leap Years.*

X



xanthophyll \'zan(t)-thə-ˌfil\ *n.*

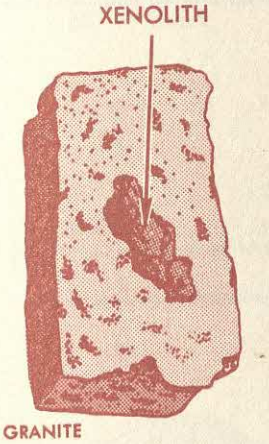
BIOLOGY. One of a group of usually-yellow pigments often present in the plastids of plants and the fats of animals.

XANTHOPHYLL *can be seen easily in green grass that has been covered with a board for several days.*

x-axis \'ek-ˌsak-səs\ *n.*

MATHEMATICS. Of the two axes of a two-dimensional coordinate system, the axis that is generally horizontal; also, that axis of the three axes of a three-dimensional coordinate system that passes through the intersection of the y-axis and the z-axis and is generally perpendicular to both.

A line parallel to an X-AXIS *has a slope equal to zero.*



X chromosome \'eks 'krō-mə-ˌsōm\

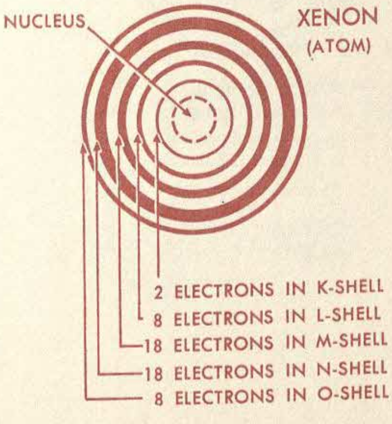
BIOLOGY. The chromosome that determines the sex of an organism. It is the element and carrier of heredity that promotes the development of female characteristics. Each female cell contains two X chromosomes, while each male cell has one X and one Y; see Y *chromosome.*

In fruit flies, as in man, the union of an X CHROMOSOME *and a Y chromosome results in a male offspring, while the combination of two X chromosomes produces a female.*

xenolith \'zen-ᵊl-ˌith\ *n.*

EARTH SCIENCE. A rock fragment found within some igneous rocks, but of different origin from the igneous rock; also, a fragment of rock within another rock.

The presence of a XENOLITH *in a block of granite may make the granite unsuitable for use as building stone.*



xenon \'ze-ˌnän\ *n.*

CHEMISTRY. A rare, inert gas that occurs in air but makes up less than 0.0001 percent of the volume of air. Symbol, Xe; atomic number, 54; atomic weight, 131.30.

The "strobe" light used by a photographer is a tube of XENON *which produces a brief but very bright flash of light whenever an electric current passes through it.*

xerophytes \'zir-ə-ˌfīts\ *n.*

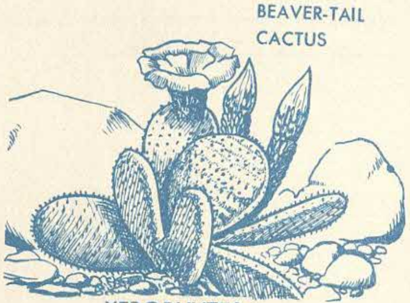
BOTANY. Plants, such as cacti or sagebrush, that are adapted to grow in a dry habitat; see *mesophytes* and *hydrophytes.*

XEROPHYTES *are characterized by such adaptations as a waxy epidermis, water-storage tissue and small leaves or none.*

xiphoid process \'zif-ˌȯid 'präs-ˌes\

ANATOMY. The lower portion of the sternum (breastbone), which forms a narrow point below the attachment of the ribs, and which usually remains cartilaginous throughout life.

The Greek word for "sword" suggested the name of the blade-shaped XIPHOID PROCESS.



XEROPHYTES

X ray \'eks-ˌrā\ *n.*

MEDICINE and PHYSICS. One of several penetrating electromagnetic radiations of very short wavelength that occurs between the wavelengths of ultraviolet radiation and gamma rays (10^{-6} to 10^{-9} centimeters). X rays are produced when substances (atoms) are struck by high-speed electrons. They cause exposure of photographic film and ionization of substances that absorb them; see *roentgen.*

Properly used, the X RAY *provides a valuable means of diagnosing internal injuries of the human body.*

X-ray spectrum \'eks-ˌrā 'spek-trəm\

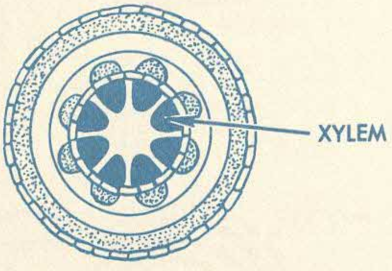
CHEMISTRY and PHYSICS. A particular group of X rays of certain wavelengths given off by an element, as a result of being bombarded by high-speed electrons. An X-ray spectrum varies according to the element emitting the X rays.

Analyzing the X-RAY SPECTRUM *of an unknown substance can provide information on the elements the substance contains.*

xylem \'zī-ləm\ *n.*

BOTANY. Plant tissue that conducts water from roots to leaves. In bulk, xylem forms wood and consists of tracheids, vessels, fibers and parenchyma cells.

Growth rings result from the differences seen in XYLEM *formed early in the growing season and that formed late.*



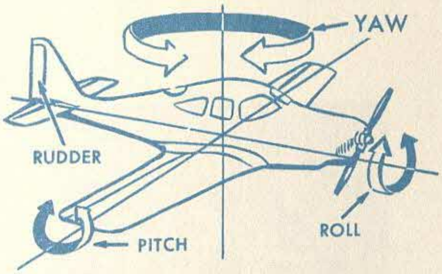
CROSS SECTION OF PLANT STEM

xylene \'zī-ˌlēn\ *n.*

CHEMISTRY. C_8H_{10}. A colorless liquid that burns easily. It is useful as a solvent for many organic substances and is used in making rubber cement.

XYLENE *is usually obtained from petroleum as a mixture of three isomers: ortho-xylene, meta-xylene and para-xylene.*

Y

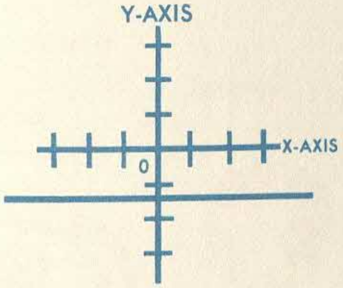


yard \'yärd\ *n.*
MATHEMATICS. A unit of length equal to 3 feet, or 36 inches; *abbr.* yd.

The YARD *is used to measure cloth.*

yaw \'yȯ\ *n.*
AERONAUTICS and ASTRONAUTICS. The movement of an aircraft, rocket or space vehicle around its vertical axis; in the case of an airplane in a normal attitude, a change in direction to the right or left.

The movement of an airplane's rudder produces YAW.

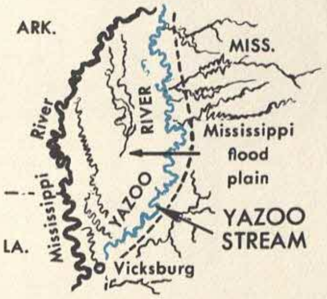


y-axis \'wī-ˌak-səs\ *n.*
MATHEMATICS. Of the two axes of a two-dimensional coordinate system, the axis that is generally perpendicular; also, of the three axes of a three-dimensional coordinate system, the axis that is usually located at right angles to the x-axis and to the z-axis and that passes through their intersection.

A function whose graph is symmetrical with respect to the Y-AXIS *is called an even function.*

yazoo stream \'ya-zü 'strēm\
EARTH SCIENCE. A tributary that runs for some distance parallel to the main stream before joining it.

The term YAZOO STREAM *was derived from the Yazoo River, a tributary of the Mississippi River.*



Y chromosome \'wī 'krō-mə-ˌsōm\
BIOLOGY. The partner of the X chromosome in the cell nuclei of many male organisms. It is involved in determining the sex of an individual insofar as its presence excludes a second X chromosome; see *X chromosome.*

The Y CHROMOSOME *in fruit flies has a J shape, while the X chromosome is rod-shaped.*

year \'yi(ə)r\ *n.*
ASTRONOMY. The time it takes the earth to make one revolution around the sun; a unit for measuring time that, in the case of

the tropical year, is equal to 365 days, 5 hours, 48 minutes and 46 seconds.

The sidereal YEAR *is 20 minutes and 21.5 seconds longer than the tropical year.*

yeasts \'yēsts\ *n.*

BOTANY and CHEMISTRY. Usually, one-celled fungi 4 to 20 times larger than true bacteria. Yeasts have a nucleus and often reproduce by budding. Certain kinds secrete enzymes that cause fermentation by breaking down carbohydrates in solution to form alcohol and carbon dioxide; see *zymase.*

YEASTS *may be collected from the surface of fruits, the sap of trees or the nectar of flowers.*

YEASTS (BUDDING)

yield \'yēld\ *n.*

1. PHYSICS. The total amount of energy released in a nuclear explosion, measured in terms of the tons of TNT that, when exploded, would release the same amount of energy. 2. CHEMISTRY. The weight of product resulting from a chemical reaction; frequently, the weight of actual product expressed as a percentage of the weight predicted by theoretical calculations.

The YIELD *produced by a hydrogen bomb is so enormous that new terms of measurement, such as megaton, have been developed.*

yield point \'yēld 'pȯint\

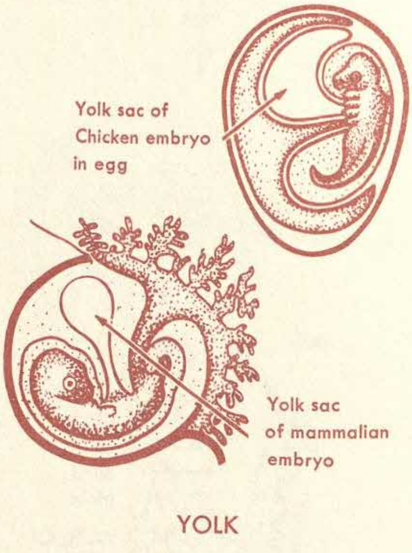
PHYSICS. The smallest force, or stress, that will cause an object to undergo bending, stretching or some other permanent change of shape; see *elastic limit.*

A metal spring that has been stretched so far that it does not return to its original shape has passed its YIELD POINT.

yolk \'yōk\ *n.*

ZOOLOGY. A fatty, protein substance found in granules in the cytoplasm of eggs. The yolk serves as food for the developing embryo.

An egg YOLK *contains a number of proteins, plus cholesterol and fats.*


Yolk sac of Chicken embryo in egg
Yolk sac of mammalian embryo

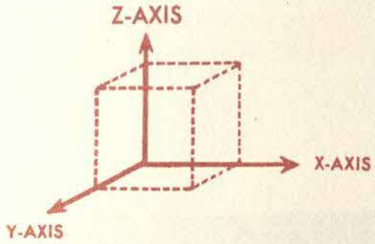
YOLK

y-organ \'wī-'ȯr-gən\ *n.*

ZOOLOGY. A glandular structure which is located in the head region of a crustacean and produces a hormone that stimulates molting.

Hormones produced by the Y-ORGAN *interact with molt-inhibiting hormones produced by the sinus gland located in the eyestalk to control cyclical changes in the body of the crayfish.*

Z



z-axis \'zē-ˌak-səs\ *n.*

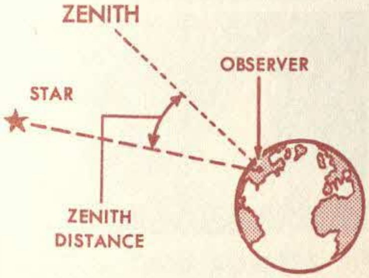
MATHEMATICS. Of the three axes of a three-dimensional coordinate system, that axis that passes through the intersection of the x-axis and the y-axis and is usually perpendicular to both.

The point at which the x-axis, y-axis and Z-AXIS *intersect is called the origin.*

zenith \'zē-nəth\ *n.*

ASTRONOMY. On the celestial sphere, the point that is directly above an observer.

The zenith distance of a star is the angular distance from the ZENITH *to the star.*



zeolite \'zē-ə-ˌlīt\ *n.*

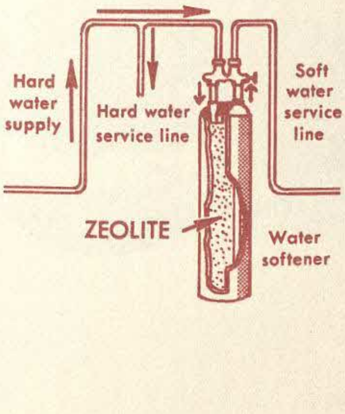
CHEMISTRY. A mixture of sodium aluminum silicate compounds found as a natural mineral and used to soften hard water.

A ZEOLITE *softens hard water by removing calcium and magnesium ions and substituting sodium ions for them.*

zeppelin \'zep-(ə-)lən\ *n.*

AERONAUTICS. A type of large, rigid airship, or dirigible, developed by Count von Zeppelin and first built in 1900.

The "Hindenberg," a ZEPPELIN *built in Germany in 1936, was 814 feet long and had a diameter of 135 feet.*



zero gravity \'zē-(ˌ)rō 'grav-ət-ē\

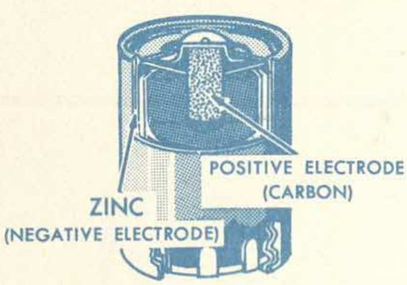
PHYSICS. The condition of weightlessness within a container, such as a capsule, when the container is falling freely toward the earth or is in unpowered orbital motion. Zero gravity results from the fact that there is no difference in gravitational pull on the container and on the container's contents. Thus, everything within the container floats, or has no weight with reference to the container; see *free fall.*

The contents of a space capsule in orbit are weightless, or in a condition of ZERO GRAVITY, *since both the capsule and contents are falling at the same speed.*

zero group \'zē-(ˌ)rō 'grüp\

CHEMISTRY. The inert gases. They differ from the other elements in the periodic table in that they will not easily combine with other elements. Gases in the zero group have atoms that contain a complete outer electron shell.

The gases helium, neon, argon, krypton and xenon, plus the radioactive element radon, form the ZERO GROUP *of elements.*



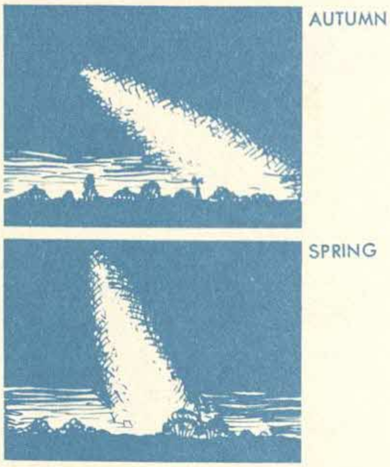
DRY CELL

zinc \'ziŋk\ *n.*
CHEMISTRY. A metallic element, bluish white in color and about as dense as tin. It is useful in galvanizing steel and making brass; its compounds are used in paint, insecticides and medicine. Symbol, Zn; atomic number, 30; atomic weight, 65.37.

ZINC *serves both as the case and the negative electrode of the common flashlight cell.*

zodiacal light \zō-'dī-ə-kəl 'līt\
ASTRONOMY. A faint glow of light that sometimes extends up from the horizon along the path of the sun. Zodiacal light is seen in spring or fall just after sunset or before sunrise.

ZODIACAL LIGHT *is thought to be caused by small particles of dust that reflect sunlight.*



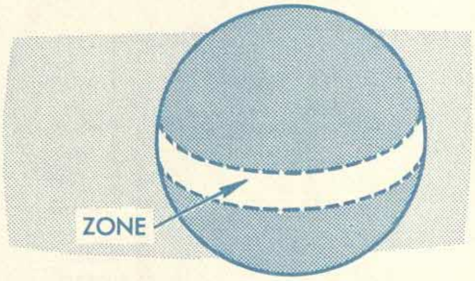
ZODIACAL LIGHT

zone \'zōn\ *n.*
1. MATHEMATICS. A portion of the surface of a sphere between two parallel planes intersecting the sphere. 2. EARTH SCIENCE. Any of the earth's climatic divisions that are fixed by the Arctic and Antarctic circles and by the tropics of Cancer and Capricorn; see *Frigid Zone, Temperate Zone* and *Torrid Zone;* also, a rock bed or an area characterized by a common property, such as minerals or fossils.

The bases of a ZONE *are the circles formed by the intersection of parallel planes with the sphere.*

zone purification \'zōn ˌpyu̇r-ə-fə-'kā-shən\
CHEMISTRY. A process by which impurities are removed from certain metals or crystalline compounds. In operation, a bar of the metal, or a tube of the compound, is moved slowly through a device that heats a small portion of the bar or tube to a temperature near the melting point of the substance. Impurities concentrate in the hot region, or zone, and are eventually trapped at one end of the bar or tube.

ZONE PURIFICATION *has been used to prepare germanium metal for use in transistors.*



zoologist \zō-'äl-ə-jəst\ *n.*
ZOOLOGY. A scientist who studies animal life.

A ZOOLOGIST *with a special interest in birds may also be called an ornithologist.*

zoology \zō-ˈäl-ə-jē\ *n.*

The branch of biology that deals with the life, structure, development and classification of animals; broadly, the science of animals or animal life.

The study of microorganisms may be included in either ZOOLOGY *or microbiology.*

ZOOPHYTE

zoophyte \ˈzō-ə-ˌfīt\ *n.*

ZOOLOGY. One of a number of invertebrate animals that resemble plants, as a coral or sponge.

A ZOOPHYTE *is usually an aquatic animal lacking locomotion at a prominent stage of its development.*

zoospore \ˈzō-ə-ˌspō(ə)r\ *n.*

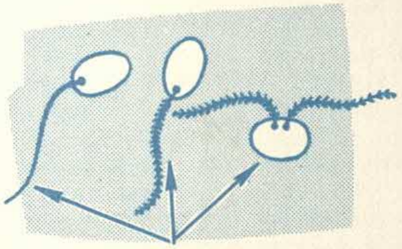
1. BOTANY. An asexual reproductive cell capable of locomotion by flagella. It is produced by some aquatic plants that do not possess reproductive tissues. 2. ZOOLOGY. A free-moving flagellate, or amoeboid, body that comes from the sporocyst of some protozoans.

When mature, a ZOOSPORE *escapes from its cell wall, swims freely for a time, then becomes attached and grows into a new individual.*

zygote \ˈzī-ˌgōt\ *n.*

BIOLOGY. A fertilized egg, or cell, that results from the fusion of two gametes; also, the individual that results from a fertilized egg.

A ZYGOTE *divides and subdivides by mitosis, forming an individual of the same kind as the parent.*



ZOOSPORE

zymase \ˈzī-ˌmās\ *n.*

BIOLOGY. A mixture of enzymes, produced by yeast, that catalyzes the decomposition of glucose and certain other sugars into carbon dioxide and ethyl alcohol (fermentation).

Yeasts contains enzymes other than ZYMASE *that will break down carbohydrates into simple sugars.*

zymolysis \zī-ˈmäl-ə-səs\ *n.*

BIOLOGY and CHEMISTRY. A chemical reaction that breaks down complex organic compounds into simpler compounds and that is caused by the presence of other compounds called enzymes; also called enzymolysis; see *enzyme.*

ZYMOLYSIS *is the principal type of chemical reaction that occurs in the digestion of food.*

COMPLETE INDEX FOR WORLD OF SCIENCE

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"Workbook in General Botany", Rev. ed., H. C. Sampson, copyright 1941, 1949, Harper & Row, Publishers, Inc. (New York): 11(3)
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